1926

LAW
[illegible]
WITHDRAWN

~~NORTH BUILDING LIBRARY~~

~~MYCOLOGY LIBRARY~~

@BLDSC
0020980

DEPARTMENT
OF
PLANT PATHOLOGY
ROTHAMSTED EXPERIMENTAL STATION
HARPENDEN, HERTS. ENGLAND

WITHDRAWN

632: 633

25/ nett

Digitized by the Internet Archive
in 2022 with funding from
Kahle/Austin Foundation

https://archive.org/details/citrusdiseasesth0000howa

McGRAW-HILL PUBLICATIONS IN THE
AGRICULTURAL AND BOTANICAL SCIENCES
CHARLES V. PIPER, CONSULTING EDITOR

CITRUS DISEASES AND THEIR CONTROL

McGRAW-HILL PUBLICATIONS IN THE AGRICULTURAL AND BOTANICAL SCIENCES

Charles V. Piper, Consulting Editor

Adams—
FARM MANAGEMENT

Babcock and Clausen—
GENETICS IN RELATION TO AGRICULTURE

Babcock and Collins—
GENETICS LABORATORY MANUAL

Boyle—
MARKETING OF AGRICULTURAL PRODUCTS

Carrier—
BEGINNINGS OF AGRICULTURE IN AMERICA

Crucss—
COMMERCIAL FRUIT AND VEGETABLE PRODUCTS

Cruess and Christie—
LABORATORY MANUAL OF FRUIT AND VEGETABLE PRODUCTS

Eames and MacDaniels—
AN INTRODUCTION TO PLANT ANATOMY

Emerson—
SOIL CHARACTERISTICS

Gardner, Bradford and Hooker—
FUNDAMENTALS OF FRUIT PRODUCTION

Hayes and Garber—
BREEDING CROP PLANTS

Hutcheson and Wolfe—
THE PRODUCTION OF FIELD CROPS

Loeb—
REGENERATION—FROM A PHYSICO-CHEMICAL VIEWPOINT

Löhnis and Fred—
TEXTBOOK OF AGRICULTURAL BACTERIOLOGY

Piper and Morse—
THE SOYBEAN

Sharp—
AN INTRODUCTION TO CYTOLOGY
Second Edition

Sinnott—
BOTANY: PRINCIPLES AND PROBLEMS

Sinnott and Dunn—
PRINCIPLES OF GENETICS

Thatcher—
THE CHEMISTRY OF PLANT LIFE

Thompson—
VEGETABLE CROPS

Weaver—
ROOT DEVELOPMENT OF FIELD CROPS

Fawcett and Lee—
CITRUS DISEASES AND THEIR CONTROL

McGRAW-HILL PUBLICATIONS IN THE ZOÖLOGICAL SCIENCES

Dr. A. Franklin Shull, Consulting Editor

Fernald—
APPLIED ENTOMOLOGY
Second Edition

Mitchell—
TEXTBOOK OF GENERAL PHYSIOLOGY

Shull, Larue and Ruthven—
PRINCIPLES OF ANIMAL BIOLOGY

Shull, Larue and Ruthven—
LABORATORY DIRECTIONS IN PRINCIPLES OF ANIMAL BIOLOGY

Snodgrass—
ANATOMY AND PHYSIOLOGY OF THE HONEYBEE

Van Cleave—
INVERTEBRATE ZOOLOGY

Wieman—
GENERAL ZOOLOGY

Shull—
HEREDITY

Pearse—
ANIMAL ECOLOGY

OF
PLANT PATHOLOGY
ROTHAMSTED EXPERIMENTAL STATION
HARPENDEN, HERTS., ENGLAND

CITRUS DISEASES
AND
THEIR CONTROL

BY

HOWARD S. FAWCETT
Professor of Plant Pathology, Graduate School of Tropical Agriculture and Citrus Experiment Station, University of California. Formerly Plant Pathologist, Florida Agricultural Experiment Station

WITH SECTIONS ON
ORIENTAL CITRUS DISEASES
BY

H. ATHERTON LEE
Plant Pathologist, Experiment Station, Hawaiian Sugar Planters Association. Formerly Plant Pathologist, Philippine Bureau of Science

FIRST EDITION

McGRAW-HILL BOOK COMPANY, INC.
NEW YORK: 370 SEVENTH AVENUE
LONDON: 6 & 8 BOUVERIE ST., E. C. 4
1926

M/L
634

Copyright, 1926, by the
McGraw-Hill Book Company, Inc.

PRINTED IN THE UNITED STATES OF AMERICA

THE MAPLE PRESS COMPANY, YORK, PA.

To those interested in maintaining the health of Citrus trees and fruits the world over, and in particular to those who, by encouragement, suggestion and cooperation, are aiding basic investigations to that end, this book is dedicated.

PREFACE

We have attempted to present in this book a discussion of the present information on Citrus diseases occurring in all parts of the world where Citrus fruits are grown. The need for such a publication has been brought frequently to our attention by growers and students interested in Citrus culture.

It is hoped that this book may serve not only as a guide to growers in the identification of the diseases, diagnosis as to their causes and application of control measures in so far as these are known, but may also serve as a source of information to students and investigators who are to pursue in this special field further scientific research, which is still so abundantly needed.

We have attempted to indicate throughout the book by frequent references to the bibliography the scattered literature on which certain parts of our information is based. Although one of us in the western hemisphere and the other in the eastern have had the opportunity to investigate personally a large number of the diseases herein described and to observe at first hand most of the other diseases, we have aimed to recognize the great value of the numerous contributions by other investigators, past and present, in the same field. This is referred to specifically in the section entitled History of Citrus-disease Investigations, in Chap. I.

We should not fail to recognize the great part the Citrus industry itself has played in affording material for experimentation and in giving encouragement to various investigators and research institutions. This has made possible some of the most important scientific investigations on which this publication in a great measure is based.

The junior author has prepared the discussions and illustrations dealing with Citrus canker, bark rot, rubellosis or pink disease, powdery mildew, hyaline rot, inspissosis, black spot, anthracnose of Satsumas, Phyllosticta leaf spot, parts each of Diplodia rot and Loranthus and the colored illustrations for scab. He has also prepared the discussion of the distribution of Citrus diseases in China, Japan, India, the Philippines and the East Indies in Chap. III, and the part pertaining to the subject of Exclusion in Chap. V, together with insertions within other subjects.

In the preparation of this book there has been the encouragement and help of many associates and friends. We wish to acknowledge, first of all, the valuable aid given by the Lemon Men's Club of California in making possible ten of the fifteen colored plates for this treatise.

We are indebted especially to H. J. Ramsey and Dr. J. T. Barrett for reading the entire manuscript and for valuable suggestions connected therewith, and to Dr. O. F. Burger for helpful suggestions on most of the parts dealing with the Florida diseases. Special parts of the manuscript have been read by G. L. Peltier, H. J. Webber, W. T. Swingle, E. D. Merrill, H. S. Reed, A. R. C. Haas, J. E. Coit, R. W. Hodgson, E. E. Thomas, E. T. Bartholomew, C. O. Smith, W. P. Kelley, H. B. Frost, R. E. Smith, W. T. Horne, H. R. Fulton, Anna E. Jenkins, R. S. Woglum, H. J. Quayle, W. W. Yothers, H. W. Nixon, W. A. Barger, A. E. Nelson and T. Helen Fawcett, to whom thanks are gratefully extended. For help in the formation of most of the new latinized names for diseases, thanks are due Dr. W. A. Setchell of the University of California.

Certain photographs were furnished by Dr. O. F. Burger of the Florida Experiment Station, by Prof. W. T. Horne of the California Experiment Station and others. The authorship for all illustrations that are not original is acknowledged under each description. The copies for the colored illustrations on canker, rubellosis, Phyllosticta leaf spot, anthracnose of Satsuma and part of scab were made by Mrs. H. A. Lee of Honolulu, T. H., the remainder by Mr. and Mrs. Avery Fields of Riverside, Cal. We are indebted to Prof. Louis Montchal for valuable aid in the translation of parts of certain Italian, Spanish and Portuguese papers on Citrus diseases, and to Louis L. Huillier for manifold laboratory assistance.

Many others whose assistance is acknowledged in the body of the book have aided by furnishing information regarding diseases in different countries.

The authors will be glad to have their attention called to any possible mistatements, errors or important omissions in this edition.

H. S. Fawcett.
H. A. Lee.

Riverside, Cal.
Honolulu, T. H.,
September, 1925.

CONTENTS

PAGE
PREFACE vii

PART I

GENERAL CONSIDERATIONS

INTRODUCTION 1
CHAPTER
I. HISTORY OF CITRUS-DISEASE INVESTIGATIONS; SPECIES AND VARIETIES; STRUCTURE AND PHYSIOLOGY OF CITRUS 5
II. CLASSES AND TYPES OF CITRUS DISEASES; NATURE AND CLASSIFICATION OF FUNGI 18
III. GEOGRAPHICAL DISTRIBUTION OF CITRUS DISEASES 28
IV. CONDITIONS AFFECTING SEVERITY AND DISTRIBUTION OF CITRUS DISEASES 34
V. GENERAL PRINCIPLES OF PREVENTION AND TREATMENT OF CITRUS DISEASES 39
VI. FUNGICIDES, DISINFECTANTS, PAINTS AND WAXES 48
VII. CULTURAL OPERATIONS IN RELATION TO CITRUS DISEASES 64

PART II

ROOT AND TRUNK DISEASES 81

INTRODUCTION 83
KEY TO THE ROOT AND TRUNK DISEASES 84
VIII. ROOT DISEASES 89
  Armillaria root rot 89
  Rosellinia root rot 98
  Sclerotinia root rot 103
  Dry root rot 105
  Poria fungus on roots 109
  Water injury 109
  Citrus nematode 113
  Insect injury to roots 118
  Gas and oil injury 120
IX. DISEASES OF CROWN ROOTS AND BASE OF TRUNK 121
  Gummosis in bark diseases 121
  Historical review of gum disease of crown roots and trunk 122
  Pythiacystis gummosis 125

Chapter Page

Mal di gomma 146
Sclerotinia gummosis 153
Rodent injury 154
Fumigation injury to trunk and roots 155

X. Diseases of Trunk and Main Branches 158
Psorosis 158
Bark rot 171
Decorticosis or shell bark 176
Botrytis gummosis 183
Diplodia gummosis 190
Dothiorella gummosis 191
Concave gum disease 192
Blind pocket 193
Bark spot of Brazil 193
Miscellaneous types of gummosis 194
Heart rots or wood rots 196
Lichens on trunks 200
Sunburning 201
Frost injury 201

PART III

DISEASES OF BRANCHES, TWIGS AND LEAVES 205

Introduction 207

Key to Diseases of Branches, Twigs and Leaves 207

XI. Eruptive Diseases 212
Cancrosis or Citrus canker 212
Verrucosis or scab 222
Melanose 226
Greasy spot 229
Leprosis or nailhead rust 231
Lepra explosiva 240
Ring blotch 241
Exanthema 243
Gum spot of leaf 252

XII. Superficial Markings, Pustules or Coatings 253
Sooty mold 253
Powdery mildew 255
Septobasidium on twigs 257
Lichens on leaves and twigs 260
Alga spot 261
Atichia fungus 262
Scale insects and white flies 263
Entomogenous fungi 266

XIII. Dead-spot Diseases 274
Phyllosticta leaf spot 274
Phytophthora leaf blight 275
Chocolate spot 276

Chapter Page
Frost injury to leaves and twigs . . . 277
Fumigation and spray injury . . . 279
Miscellaneous leaf spots . . . 279

XIV. Diseases Resulting in Death of Entire Parts . . . 283
Anthracnose of twigs and leaves . . . 283
Citrus blast . . . 293
Rubellosis or pink disease . . . 304
Diplodia twig blight . . . 308
Sclerotinia twig blight . . . 310
Botrytis twig blight . . . 311
Citrus blight . . . 312
Thread blight . . . 314
Twig gumming . . . 315
Lightning injury . . . 315
Alkali injury . . . 318

XV. Abnormalities and General Effects . . . 322
Sphæropsis knot . . . 322
Citrus galls . . . 326
Witches'-broom . . . 327
Crinkly leaf . . . 329
Insect effects . . . 330
Chlorosis . . . 334
Foliocellosis . . . 336
Parasitic flowering plants . . . 341

PART IV

FRUIT DISEASES

Introduction . . . 347

Key to the Fruit Diseases . . . 347

XVI. Fruit Rots . . . 353
Common green mold . . . 353
Blue-contact mold . . . 357
Pink mold . . . 362
Trichoderma rot . . . 364
Aspergillus rot . . . 365
Rhizopus rot . . . 366
Rolf's sclerotium rot . . . 367
Oöspora rot or sour rot . . . 369
Pythiacystis rot or brown rot . . . 372
Phythophthora rot . . . 379
Sclerotinia rot or cottony rot . . . 380
Botrytis rot . . . 385
Hyaline rot . . . 388
Alternaria rot of lemons . . . 389
Pleospora rot . . . 393
Alternaria rot or black rot of oranges . . . 393
Anthracnose rot . . . 396
Fusarium rot . . . 398
Stylar-end rot of Persian limes . . . 399

CHAPTER PAGE
Phomopsis stem-end rot 401
Diplodia rot 409
Dothiorella rot 412
Charcoal rot 414
Inspissosis or dry rot 415

XVII. INTERNAL NON-PARASITIC MALADIES AND GENERAL EFFECTS 421
Endoxerosis or internal decline 421
Hollow core 426
Juice-sack granulation 426
Membranosis or membranous stain 428
Frost injury 429
Carpoptosis or excessive fruit drop 435
Fruit gumming 439

XVIII. EXTERNAL SPOTS, MARKINGS AND ERUPTIONS 440
Adustiosis or red blotch 440
Peteca 441
Albedo browing 443
Black-pit form of citro-necrosis 443
Bacterial spot of South Africa 450
Anthracnose stains and spots 454
Alternaria spot 464
Cytosporina spot and rot of Mandarin oranges 465
Oleocellosis 466
Brown spot of the Navel orange 472
Storage spot or "Pox" 474
Septoria spot 477
Black spot 479
Cancrosis or Citrus canker on fruits 482
Leprosis or nailhead rust 483
Verrucosis or Citrus scab 485
Melanose 496
Flyspeck fungus 500
Exanthema 501
Exobasidium disease of Mandarin oranges 503
Rust-mite injury to fruits 503
Tear staining of fruits 505
Thrips injury 506
Wind injury 509
Fumigation injury 513
Spray injury to fruits 515
Splits 517
Creasing and puffing 520
Miscellaneous spots and blemishes 520

XIX. GENERAL PROBLEMS OF DETERIORATION AND DECAY OF CITRUS FRUITS 525
Problems of decay and deterioration of Citrus fruits from the tree to the market 525
Special problems of decay and deterioration in lemon fruits 529

BIBLIOGRAPHY 543

INDEX 561

CITRUS DISEASES AND THEIR CONTROL

INTRODUCTION

To one with brief experience in Citrus culture, the long array of diseases in this treatise may at first seem appalling and might tend to discourage further interest in the subject. In any given country or any given locality, however, only a few of these diseases are apt to assume major importance. Many of them may be rare or of minor importance, and others may be entirely absent. The differences in climatic and other conditions between two countries, or even two localities in the same country, may be so great as to make diseases that are major in one place minor or of no economic importance in the other. Major diseases of one variety may be minor in another. Then, again, many of the diseases herein discussed are aggravated by neglect or mismanagement in cultural or other conditions and are preventable with the exercise of due care. A few, however, are of a most serious nature and frequently require the most drastic measures and constant attention in the use of means for their prevention or treatment.

Viewed from the standpoint of the whole industry, the presence of these diseases is perhaps indirectly a benefit in its ultimate effect, since it serves as one of the natural checks on overproduction. The problem presented by their successful prevention and control also tends to add interest and zest to the growing of Citrus fruits.

The discussion of the specific diseases is arranged for convenience of reference and identification into groups corresponding, in general, to the parts of the tree affected: (1) roots and trunk; (2) branches, twigs and leaves; and (3) fruit; and in accordance with the general appearance or similarity of the lesions or effects. Keys are provided for further aid in identification.

Disease is considered here in a broad sense, as defined by Marshall Ward and as applied to economic conditions by Link and Gardner (1919), to include any condition of the plant or its parts resulting from a deviation from the usual or normal structure or function sufficient to threaten life or impair the economic usefulness. This brings into consideration effects due to environmental and nutritional influences as well as those due to organisms. The diseases due to fungi, however, have here received the most attention.

A few of the diseases due to insects and other animal organisms have been included because the lesions or effects are frequently mistaken for those due to vegetable parasites or because the injuries serve as contributory factors for infection and development of the latter.

PART I

GENERAL CONSIDERATIONS

CHAPTER I

HISTORY OF CITRUS-DISEASE INVESTIGATIONS; SPECIES AND VARIETIES OF CITRUS; STRUCTURE AND PHYSIOLOGY OF CITRUS

HISTORY OF CITRUS-DISEASE INVESTIGATIONS

It was only after Citrus culture had become of considerable commercial importance that extended scientific investigations of the diseases were begun. Most of the earlier literature on Citrus diseases appears to have been by Italian writers. Some of the earliest scientific papers written from a pathological viewpoint were those by L. Savastano, beginning about 1884. Other Italian writers on Citrus diseases of about the same time were G. Briosi and O. Comes. Savastano (1910) refers to a number of earlier Italian writers on Citrus diseases. Among these was G. Inzenga, who published many papers between about 1864 and 1878. Before 1884 mycologists, especially in Italy, had begun to study some of the fungi occurring on Citrus, but these studies were concerned more especially with the fungi themselves than with the relation they might have to specific diseases. The methods of control before that time were left largely to the orchardist, who often practiced crude and unscientific means of treatment, many of them apparently handed down from the remote past and involved in magic and superstition.

In the field of Mycology, Penzig as early as 1887 published an extensive monograph on the Citrus fungi, in which he carefully described and illustrated by drawings 160 species of the fungi found on the live or dead parts of Citrus in southern Europe. An important monograph on the diseases and the fungi occurring on Citrus in Australia was published by McAlpine in 1899. McAlpine's work (1899) was primarily that of a mycologist, but he also studied and described the symptoms of the diseases as well. F. Noack (1900) published an account of Citrus diseases found in Brazil, with descriptions of fungi associated therewith.

The first extensive scientific investigations of Citrus diseases in the United States from the standpoint of cause and control were begun by W. T. Swingle and H. J. Webber in 1892. A field laboratory organized especially for that purpose by W. T. Swingle of the U. S. Department of Agriculture was established at Eustis, Fla. Previous to that time beginning with 1886 some study and observations, mostly of a mycological nature, were given to Citrus diseases by the U. S. Department of Agriculture. F. L. Scribner, L. M. Underwood and B. T. Galloway contributed to a preliminary study of the diseases and nature of the fungi. In 1891, L. M. Underwood had made a preliminary survey of the Florida Citrus diseases and W. T. Swingle a preliminary study of Citrus blight and other diseases. W. T. Swingle and H. J. Webber contributed much to the knowledge of blight, exanthema, scab, mal di gomma, melanose and sooty mold. Swingle and Webber's (1896) work on "The Principal Diseases of Citrus Fruits in Florida" served as a foundation for later investigations on Citrus-disease control in Florida and other countries. Their bulletin was translated into Japanese by the Formosan government and has been also widely quoted and referred to in later publications on Citrus diseases in other countries. In Florida, the work of Swingle and Webber was followed some years later by that of P. H. Rolfs (1904), who made an investigation of the anthracnose of limes and other Citrus fruits. H. H. Humes' (1900, 1904) observations and experiments on Citrus diseases in Florida occurring at about the same period should also be mentioned.

In the last twenty years, beginning about 1905, investigations in Citrus diseases have been continuously carried on by H. S. Fawcett, first in Florida to 1912 and later in California. During the same period, Citrus-disease investigations have been made by B. F. Floyd, H. E. Stevens, O. F. Burger and others at the Florida Agricultural Experiment Station; by G. L. Peltier, F. A. Wolf and others in the other Gulf states; and by Clara H. Hasse, J. G. Grossenbacher, Florence Hedges, H. R. Fulton, J. R. Winston and Anna E. Jenkins and others of the U. S. Department of Agriculture. Special investigations on fruit decay is mentioned later.

In Florida during this latter period attention has been directed especially to solving the problems connected with the cause and control of scab, melanose, Phomopsis and Diplodia stem-end rots, exanthema, leprosis or nailhead rust, mal di gomma and Citrus canker. The causes, nature of development and control of many of these have been worked out. Many unsolved problems, however, still remain to be investigated in connection with these diseases.

In California the first scientific work on Citrus diseases was begun by N. B. Pierce of the U. S. Department of Agriculture, who published a short paper on black rot of the navel orange (1902). C. W. Woodworth (1902) also published a paper on Penicillium rot.

The first extended investigation of Citrus diseases in California, however, was that by R. E. Smith and his coworkers, O. Butler, Elizabeth Smith, C. O. Smith, H. J. Ramsey, J. E. Coit and others. The University of California greatly facilitated these investigations by the establishment in 1905 of the Southern California Pathological Laboratory in the midst of the Citrus-growing districts at Whittier. The contributing factors, the cause and the control of a number of Citrus diseases were studied. One of the early investigations of scientific interest which was of great economic importance in this period was that of the cause and control of the brown rot of Citrus fruits, especially lemons, due to *Pythiacystis citrophthora*. The important investigations on blue and green mold initiated by G. Harold Powell during this period are referred to later.

An investigation of Citrus diseases in California was begun by H. S. Fawcett in 1912, first with the California State Commission of Horticulture and later with the University of California. With the establishment of the Citrus Experiment Station as a part of the California Agricultural Experiment Station in 1913, the pathological work on Citrus diseases that had been begun at the Whittier Laboratory has been continued at Riverside by J. T. Barrett, C. O. Smith, E. E. Thomas, E. T. Bartholomew and H. S. Fawcett. Investigations have been made on Pythiacystis gummosis, psorosis, Armillaria root rot, anthracnose, Sclerotinia rot, Oöspora rot, various spots and blemishes, black pit, Citrus blast, Citrus nematode, Alternaria rot and internal decline.

At the Division of Plant Pathology at Berkeley, certain Citrus-disease investigations have been carried on by W. T. Horne, R. E. Clausen, H. A. Lee and A. F. Camp with Armillaria root rot, anthracnose of lime and Citrus blast. The physiological and nutritional diseases of Citrus in California have been investigated by a large number of workers, including J. E. Coit, R. W. Hodgson on June drop; C. A. Jensen, W. P. Kelley, H. S. Reed, A. R. C. Haas and E. E. Thomas on foliocellosis, chlorosis and alkali injury.

In Cuba and the West Indies during this same period, Citrus diseases received attention by M. T. Cook and W. T. Horne, J. R. Johnston, S. C. Bruner, F. S. Earle and J. M. Rogers, J. A. Stevenson, F. W. South, W. Nowell and others. In Mexico, an account of Citrus diseases was published by G. Gandara.

In South America, following the paper by F. Noack in 1900, a number of bulletins and papers on Citrus have been published by R. Avena-Sacca in Brazil, M. S. Bertoni in Paraguay and J. N. Dracopoulas and others in Argentina. Descriptions of some of the principal diseases found in Paraguay and Argentina, as well as of many fungi occurring on Citrus, has been published by C. Spegazzini. G. L. Fawcett has also published a paper on gummosis in Argentina.

In Italy during the same period, investigations have been carried on continuously at the Experiment Station at Acireale, Sicily, by L. Savastano, who has published many papers on Citrus diseases. Among other contributions to the literature of Citrus diseases in the Mediterranean countries during the same period are those of G. G. Briosi, U. Brizi, F. Cavara, L. Petri and others in Italy, R. J. Janini in Lpain, T. E. Fahmy in Egypt and J. Dufrenoy in southern France.

In South Africa, important investigations on Citrus diseases have been made in recent years by E. M. Doidge. Previously, E. Pole Evans published an investigation of the Diplodia rot of Citrus fruits.

In Australia, H. Tryon, N. A. Cobb and others published some accounts of Citrus diseases preceding McAlpine's monograph previously referred to. Publications on Citrus diseases in recent years have been made also by G. P. Darnell-Smith, C. C. Brittlebank, G. H. Cunningham, K. M. Curtis, W. M. Carne, G. Samuels and others.

In Japan, China, the Philippines and the East Indies, investigations of a number of Citrus diseases have begun. On the foundation laid in Plant Pathology in Japan by M. Shirai and Miyabi and following the translation of Swingle and Webber's bulletin (1896) by the Formosan government, many important articles on Citrus diseases have been published in Japan, in horticultural and technical journals, especially in the *Journal of Plant Protection.* Among the authors who have published important accounts of Citrus diseases are Nishida, Ideta, Onda, Hemmi, Hori, Sawada and others. Toji Nishida (1914) published in Japanese an important book on the Citrus diseases of Japan. Teizoburo Tanaka has contributed much in his translations of Japanese papers into English, abstracts of which have been published in *Mycologia.* H. A. Lee, with the viewpoint and nomenclature of American citriculture, has contributed to a knowledge of Citrus canker, bark rot, black spot, pink disease and the distribution of Citrus diseases in the Orient. O. A. Reinking has published an account of the Citrus diseases in the Philippines, southern China and Indo-China.

In the field of prevention of decay in Citrus fruits during this same period, an investigation of great importance was that started in 1905 in California by G. Harold Powell. He was assisted in the work by A. V. Stubenrauch, L. S. Tenny, H. J. Eustace, G. W. Hosford and others. This was followed by investigations along the same line in Florida by A. Stubenrauch, L. S. Tenny, H. J. Ramsey, A. W. McKay, B. B. Pratt, E. S. Pomeroy and a number of others. Recently, Lon Hawkins, J. R. Magnus, W. R. Barger, H. R. Fulton, J. R. Winston, R. S. Hill and others have made further investigations of the control of Citrus-fruit decay and deterioration. In South Africa, recent investigations in Citrus-decay problems have been made by E. Pole Evans, M. R. H. Thomson, V. A. Putterill and G. Hobson; and in Australia, investigations of Citrus-fruit decay have been reported by D. B. Adams. The factors influencing decay, especially that from the blue and green Penicillium molds, have been so well ascertained that, by the use of this information, much of the decay from this source can now be eliminated.

SPECIES AND VARIETIES OF CITRUS AND SOME NEAR RELATIVES IN RELATION TO DISEASES

Since species and varieties of Citrus are frequently mentioned in the following pages, it seems advisable that a list of some of the more important ones be given here, with both the common and the scientific names, and, with a brief mention of their susceptibility or resistance to important diseases, where it is definitely known. The names of species and varieties are used in accordance with the classification by Swingle (1914) except for *Citrus maxima* (Burm.) Merrill (1917). For descriptions of, the species and numerous varieties reference may be made to Hume (1911), Swingle (1914), Coit (1915), Fawcett and Rendle (1920) and Davis (1924). All Citrus fruits are natives of the tropical and subtropical regions of the eastern hemisphere, mostly in southern Asia and the East Indies, a few occurring in subtemperate countries of this same part of the world. The classification of Citrus species has presented many difficulties to botanists. Dr. E. D. Merrill writes that:

> It is exceedingly difficult to determine the specific limits in Citrus because the original forms have been greatly altered by selection, cultivation and hybridization. Classification in Citrus, therefore, is in a chaotic condition. During the past forty years over thirty new species of Citrus have been proposed and described by various botanists, but it is doubtful if many of these actually represent true species. Many of them are probably natural hybrids, while others are apparently forms or varieties of some of the well-known species of the genus.

The literature on resistance and susceptibility will be referred to under discussions of the various diseases. It is very important from the standpoint not only of disease resistance, but for breeding stocks or new Citrus fruits adapted to special soils or climates, that a thorough taxonomic as well as pathological study be made of the wild relatives of Citrus.

Common or Sweet Orange, *Citrus sinensis* Osbeck (*C. aurantium* var. *sinensis* Linn. and *C. aurantium* Auct.).—The common or sweet orange, sometimes spoken of as the "round orange," is the most widely cultivated species of Citrus. Numerous varieties have originated and have been propagated and given distinctive names. This species is believed to have originated in southern China. It was not introduced into European countries until about the beginning of the fifteenth century. It was later spread by Spanish and Portuguese colonization to all parts of the western hemisphere where the climate was suitable for its growth. This species usually constitutes the largest part of the commercial Citrus plantings throughout the world. The species as a whole is susceptible to mal di gomma, Pythiacystis gummosis, psorosis, leprosis or nailhead rust, melanose and Citrus blast. It is only moderately susceptible to Citrus canker. It is highly resistant to scab, bark disease of the Orient and decorticosis.

Sour or Seville Orange, *Citrus aurantium* Linn. (*C. vulgaris* Risso and *C. bigaradia* Risso).—This species includes several forms, some with very acid pulp and others with sweet juice and bitter rind and partitions. The sour orange was probably brought to Europe before the advent of the sweet orange, about the eleventh century. It was introduced into Sicily about 1002, taken to Spain and later brought to the Americas and other parts of the world during the early colonization movements. It became naturalized in parts of Florida, where wild seedlings were dug and used as stocks during the early commercial extension of Florida Citrus culture. The fruit of this species is used for marmalade, the flowers for making perfumes and the seedling plants as stocks. The bitter-sweet orange is a Florida variety with bitter partitions and inner rind, but fairly sweet juice when mature; it is used as a resistant stock. In South Africa, a similar type is known as bitter Seville. The sour orange and the bitter-sweet are immune or highly resistant to mal di gomma, Pythiacystis gummosis and most other gum diseases, and to psorosis and decorticosis. The only important disease to which they are highly susceptible is verrucosis or scab. It is also susceptible, although not highly so, to Citrus canker and Citrus blast.

Lemon, *Citrus limonia* Osbeck (*C. limonium* Risso).—The common lemon was first introduced into Europe about the eleventh or twelfth century and, like the foregoing species, was spread to various parts of the world later. The greatest commercial development in lemon growing has occurred in Sicily and southern California. In the latter locality, lemons constitute, at present, about 20 per cent of the Citrus fruits grown. The lemon is generally much more subject to frost than the sweet orange. Lemon varieties are, as a rule, highly susceptible to Pythiacystis gummosis, mal di gomma or other gum diseases, scab and decorticosis. They are moderately to fairly susceptible to Citrus canker. They are immune or highly resistant to psorosis.

The rough lemon, a horticultural variety of *Citrus limonia,* is of doubtful origin, possibly a hybrid, occurring wild in the Everglades of southern Florida. It is used as a stock for dry, sandy soils. Unlike the common lemon, it is fairly resistant to mal di gomma and Pythiacystis gummosis. Like the common lemon, it is susceptible to scab.

The sweet lemon is another horticultural variety, probably of the same species, used extensively as a stock in India and Palestine. In the latter country under irrigation by flooding it is reported to be susceptible to Pythiacystis gummosis.

Lime, *Citrus aurantifolia* (Christm) Swingle (*C. limetta* Auct *C. lima* Lunan, *C. acida* Roxb.).—The lime is often found in a semiwild state in tropical or subtropical countries. The most common commercial variety is the Mexican or West Indian lime, which has small, thin-skinned fruit used in making limeade and bottled lime juice. Limes are usually very subject to frost injury. The Mexican lime is highly susceptible to anthracnose due to *Glœosporium limetticolum*, but other lime varieties are immune or highly resistant. Unlike the lemon, it is highly resistant to scab. Lime varieties are reported to be moderately to very susceptible to Citrus canker.

Citron, *Citrus medica* Linn.—This species of Citrus was probably the only one known to the ancient Greeks and Romans. It is grown most extensively in the Mediterranean countries, especially in Corsica. Of all the species of Citrus, the citron is one of the most susceptible to frost. It is also highly susceptible to mal di gomma and Pythiacystis gummosis. In relation to Citrus canker the varieties appear to vary from medium to fairly susceptible.

Pummelo, *Citrus maxima* (Burm.) Merrill (*C. grandis* Osbeck, *C. decumana* Linn.).—This species probably originated in the Malayan Archipelago and Asia, where many varieties and types are now found. According to Swingle (1914), the term "pummelo" has been widely used for most of the forms of this species and is a convenient name for all the varieties as a whole. In the United States the thick-skinned pummelos are usually known as Shaddocks and the thinner-skinned, commercially grown forms are known as grapefruit. It now seems inadvisable to attempt to retain the term "pomelo" for the commercial varieties. The grapefruit type of this group has recently been described as *C. maxima* var. *uvacarpa* by Merrill and Lee (1924). Fawcett and Rendle (1920) considered the grapefruit to be a distinct species, *C. paradisi* Macf. The grapefruit was probably brought by the Spaniards early in the sixteenth century to Florida, where it was first grown extensively for commercial purposes, and where its culture has developed rapidly in recent years. The grapefruit varieties, in general, are highly susceptible to Citrus canker and moderately susceptible to scab. They are somewhat susceptible to psorosis, mal di gomma and Pythiacystis gummosis, though some varieties possess considerable resistance to the last two diseases. Some of the East Indian pummelos, especially some of the varieties grown in Siam, are known to have considerable resistance to Citrus canker.

Mandarin Group of Oranges, *Citrus nobilis* Lour.—The varieties under this species have been known as the mandarin group (Hume 1911, Coit 1915), although the true mandarins, according to Swingle (1914), are included under *C. nobilis* var. *deliciosa.*

King, Citrus nobilis Lour.—The variety now known in the United States as King orange was found by Loureiro in Cochin China in the last part of the eighteenth century, but was probably not introduced into America until about 1880. It is moderately susceptible to both scab and Citrus canker.

Tangerines and True Mandarins, Citrus nobilis var. *deliciosa* Swingle (*C. deliciosa* Tenore).—They are moderately susceptible to scab and black spot and slightly to moderately susceptible to Citrus canker and psorosis. They are somewhat susceptible to mal di gomma.

Satsuma Orange or Unshiu, Citrus nobilis var. *unshiu* Swingle.—This variety is commonly grown in Japan, from which country it was introduced into Florida in 1876. It is hardy and has been planted to a considerable extent in northern Florida and other Gulf states, where it is grown on the trifoliata stock. The Satsuma is fairly susceptible to Phyllosticta leaf drop, scab, anthracnose and bark rot in the Orient, but only slightly susceptible to Citrus canker. It appears to be fairly resistant to mal di gomma, psorosis and Citrus blast, and a number of other diseases.

Calamondin Orange, *Citrus mitis* Blanco.—This species is native to the Philippine Islands. It is hardy and possibly useful as a stock. It possesses considerable resistance to Citrus canker, but is very susceptible to scab. Little is known as to its susceptibility to other diseases.

Papeda or Cabuyao, *Citrus hystrix* DC. (*Papeda rumphii Hask*).—This species is sometimes used in the Philippines as a stock. Many varieties or types occur. A round-leaved form is very susceptible to canker and slightly susceptible to scab, while a pointed-leaved form is fairly resistant to canker but very susceptible to scab.

Trifoliate Orange, *Poncirus trifoliata* Raf. (*C. trifoliata* Linn.).—This species has been known in China since ancient times and is now widely used as a stock for Satsuma in Japan and in the Gulf Coast states. It is very resistant to frost injury. It is resistant to mal di gomma, Pythiacystis gummosis and other gum diseases. It is very susceptible to Citrus canker, and moderately susceptible to scab.

Kumquat: Oval (*Fortunella margarita*); Round (*F. japonica*); Meiwa (*F. crassifolia*); and Hongkong Wild (*F. hindsii*).—The oval variety was brought to England in 1846, from the Orient. The kumquats are somewhat susceptible to Citrus canker and slightly susceptible to scab.

Australian Desert Lime, *Eremocitrus glauca* Lindl.—This shrub or small tree occurs in Queensland and New South Wales, Australia, and is resistant to severe cold and drought. It has shown a considerable degree of resistance to Citrus canker and appears to be immune to scab.

Severinia, *Severinia buxifolia* Ten. (*C. buxifolia* Poir., *Atlantia buxifolia* Oliver).—This spiny shrub or dwarf tree, native to southern China, is used as a hedge plant and may possibly be useful as a stock for Citrus. It appears to be tolerant of saline conditions, immune to both Citrus canker and scab. No other important disease has been seen affecting it.

Tabog, *Chætospermum glutinosa* (Blanco) Swingle.—This, according to Swingle, is an excellent stock on which to graft oranges and other Citrus species, provided the soil is kept warm throughout the winter. It is, he says, the best one that has been found for use in the greenhouses of the U. S. Department of Agriculture and probably may prove an excellent stock in tropical regions where the soil is warm the year round. This species is susceptible to Citrus canker. It appears to be the most distantly removed relative of Citrus that produces canker lesions typical of those occurring on Citrus. Lee (1918) found it naturally affected in the field in the Philippines, but Peltier and Frederich (1920), though able to infect it in the greenhouse, found no lesions in the field under Alabama conditions.

African Cherry Orange, *Citropsis spp.*—Several species of this genus occur in the tropical forests throughout central Africa, and may prove useful as stocks or for hybridization. H. Boyle writes Dr. Swingle that *Citropsis gabonensis* (Engl) Swingle (1914) has recently come into use as a Citrus stock in the Belgian Congo. *Citropsis schweinfurthii* (Engl) Swingle may also be readily used as a stock or scion in connection with Citrus. *Citropsis schweinfurthii,* which has been tested for Citrus canker by Lee and by Peltier, appears to be infected only in wounds, producing small non-typical lesions.

Hybrids.—Many new Citrus hybrid types have been originated, some of which have given promise horticulturally either as fruits or stocks. Among these are the tangelos (tangerine × pummelo), which are somewhat susceptible to canker and slightly susceptible to scab; the citranges (trifoliate orange × common orange), which are moderately susceptible to both canker and scab; the limequat (West Indian lime × round kumquat), which is fairly susceptible to canker and highly resistant to scab and lime anthracnose; and the citrangequat (Willits citrange × oval kumquat), which is very resistant to canker but very susceptible to scab. For other varieties, species and hybrids reference may be made especially to the publications by Swingle.

STRUCTURE AND PHYSIOLOGY OF CITRUS

In every disease, whether it be parasitic or non-parasitic in nature, the effect or lesion in most cases is a result of an interaction between the internal forces or make-up of the plant and some external agency or factors. A knowledge of the structure and physiology of the host tissues affected by a disease as well as an understanding of the parasitic or contributing conditions often leads to a better understanding of the methods of its dissemination, and the character and degree of injury.

In case of a fungus disease there is, as it were, a fight between two organisms, the parasitic fungus plant on the one hand and the green host plant on the other. The resulting lesions or effect depends to a great extent on the structure and physiology of the host plant. The lesions may be dead parts, cankers, scabs, galls, loss of color or vigor, depending very much on the result of the battle between these two forces. It is therefore important in considering the nature of the diseases to have in mind the main facts and principles regarding the structure and physiology of the tree. There is still a large field for additional research into the anatomy and physiology of Citrus tissues both in health and disease.

The Citrus tree as a whole may be considered in at least four parts: (1) the roots, which serve to anchor it in the soil and to act as a means of transporting watery solutions upward and elaborated food materials downward to the growing parts; (2) the trunk and its system of branches, which serve to lift the leaves and fruit into the air and sunlight and to transport materials upward and downward; (3) the leaves, which serve under the action of light to elaborate the food materials for the growth of all parts; and finally (4) the fruit, which originally served only the purpose of reproduction, but which becomes to the Citrus grower the ultimate end and purpose of the tree's existence.

Considering the main root, trunk and branch structure and physiology, there are: (1) the bark, which serves for protection, storage and for transport of the elaborated food from the leaves to the growing parts; (2) the cambium, lying between the bark and wood, which contains the dividing and growing cells from which bark and wood are formed; and (3) the wood, which furnishes the supporting framework and channel through which the dissolved soil solutions are carried to the leaves and fruit (Figs. 72 and 150).

The main features in the anatomy of Citrus are like those of most other dicotyledenous woody plants, for details of which reference may be made to special publications on plant anatomy, such as those by W. C. Stevens (1924), Ballard (1921), Haberlandt (1914), Eames and MacDaniels (1925), etc.

The cambium is composed of delicate layers of minute, active, thin-walled, microscopic cells fitting like a multifingered glove over the woody cylinder of the roots, trunk and branches, the many fingers of this cambium opening at the ends and extending by means of numerous separate threads into the young new roots and root tips below and into the growing new shoot tips, leaves and fruit above. As the new roots or shoots mature, the spaces between the threads largely fill up till an almost continuous cambial cylinder is formed. These thin threads which spread out in the leaves and fruit are part of each bundle of tissue known as the fibrovascular bundle. The cylindrical form of the cambium in mature stems comes about, therefore, because of the close formation, in a continuous ring, of the bundles of which it is a part, and in which the inner face of the several bundles together becomes the wood and the outer face of the same bundles together becomes the inner bark elements. Thus the cambium comes to lie between the wood and the bark, serving to furnish, by multiplication of cells, increments of wood tissue on the one side and increments of bark tissue on the other. The wood cylinder and the inner bark are traversed by radiating plates seen as radiating rays in transverse section, and known as medullary rays.

These serve as means of slow lateral transfer of water or materials in the bark and wood.

The Citrus Root.—The general structure and purpose of the root have been indicated. Viewed more specifically, the bark (by which is meant all the structures from the outside to the cambium), on all except the youngest roots is made up of different sorts of tissue, the main parts being the epidermis on the outside, then the cortex and, finally, in the inner bark, the conducting tissue, made up principally of elongated sieve tubes composing the phloem. In Citrus roots the outer corky cells appear to be few, the epidermis apparently persisting a long time in the life of the root, as it does in the Citrus stems above ground.

The wood is made up of various sorts of lignified cells and traversed by elongated tubes or tracheæ through which the water and dissolved substances are transported upward toward the leaves. The medullary rays are made up of thin-walled active cells and traverse the wood and inner bark (Fig. 7).

In the very young absorbing roots this differentiation into bark and wood has not yet taken place. There are: (1) a layer of epidermal cells on the outside; (2) a number of layers of larger spherical cells composing the cortex; (3) a single layer of box-like closely fitting cells composing the endodermis or starch sheath; (4) layers, irregular in thickness, of actively dividing cells composing the pericycle; (5) within this three to five sets or groups of vascular bundles composed of sap-conducting tubes; and finally (6) in the center the thin-walled pith cells.

Some of the epidermal cells of Citrus roots frequently grow outward, forming short root hairs, but these are apparently not so common as on many other plants and are rarely noticed on roots growing in soils.

The vascular bundles are composed: (1) of thick-walled tubes composing the xylem, for conducting crude sap upward in the tree; these correspond to the conducting vessels of the wood in older roots and stems; and (2) thinner-walled tubes composing the phloem for conducting elaborated sap downward from the leaves. These correspond to the sieve-tube or phloem region of the inner bark of older roots and stems. The conducting tubes in the phloem have plates with small perforations suggesting a sieve at their ends, where one tube fits on to the next. These sieve tubes are thought to serve mainly for transportation of elaborated food materials downward to all parts of the growing roots. The watery solutions from the soil, on the other hand, pass through the epidermis and cortex of the growing roots and then into the upward conducting vessels of the xylem or wood.

The Trunk and Branches.—The bark of the trunk and branches, which bark is continuous from the roots upward, is made up principally of an outer epidermis or a few corky layers, then the cortical tissue of spherical or oval cells and finally the conducting tissues of sieve tubes next to the cambium. The sieve-tube regions of the inner bark are, of course, continuous with that of the roots and serve as channels through which the elaborated food not only supplies the branches and the trunk but also the roots below. Other structures in Citrus bark are stone cells, bast fibers, medullary ray cells and, until it is of considerable age, stomata and oil vesicles. Definite cork layers and lenticels are not usually found on the commercial species of Citrus (Figs. 48, 150 and 151).

The cambium, as before indicated, is a delicate layer of formative cells between the bark and wood from which these parts are built up. The wood is made up in stems in the manner described for roots, and the conducting vessels continue upward as sap channels to the leaves and fruit. There is no differentiation into heartwood and sapwood in Citrus, all the wood apparently carrying sap even in old trees.

Citrus Leaves.—The leaves are composed of a waxy cuticle on the exterior, an epidermal layer, a palisade layer and the spongy parenchyma of the interior.

The cuticle in most plants, according to Lee and Priestley (1924), is formed largely of fatty acid substances which during the differentiation of the tissues accumulate in the cell walls and move along them till they reach the plant surface. In the presence of oxygen these oxidize and form a varnish-like substance not dissolved by water. This film on the surface of the epidermal cells forms a rigid impermeable layer different from the cell wall underneath. The cuticle appears to be free from cellulose. An unbroken cuticle is undoubtedly a great protection against most parasitic fungi. The external conditions may have a considerable influence on formation of cuticle, and thus cause possible variation in resistance to diseases. Light has an influence on the formation of cuticle and in some plants the increase in light causes a thickening of cuticle. In general, a cuticle formed in moist atmosphere in etiolated plants may be soft and show lack of resistance to internal swelling forces. Young cuticle in plants may not be entirely impervious to water vapor, but with age it becomes more impervious and also more rigid and resistant to stretching.

The epidermis is interrupted on the under side by numerous microscopic openings, the stomata. These open into the intercellular spaces. From a disease standpoint the stomata, especially in young leaves, are vulnerable openings for certain fungus hyphæ or bacterial cells. Stomata occur also on twigs and young fruit. Through these openings exchange of gases from inside and outside take place, carbon dioxide enters the leaf and water vapor is lost by transpiration. Coit and Hodgson (1919) have found that from 40 to 50 per cent of the water loss in Citrus leaves is through the upper epidermis. They also found that early in the life of the leaf the stomata lose their power of opening and closing and remain closed thereafter. Near the surface just under the epidermis are also the oil vesicles so characteristic of Citrus leaves. The leaves are traversed by veins and veinlets, which have in them the fibrovascular bundles with the elements corresponding to inner bark (phloem), the wood (xylem) and the cambium-like cells which are connected with the stems in a continuous line. An important part of the leaf is the chlorophyll, which gives it the green color. Through its agency the sunlight is enabled to disengage the carbon from the carbon dioxide of the air and to bring about its reaction with certain compounds in dissolved substances derived from the roots, to make elaborated food materials, the starches and sugars, that may then be used in growth.

The Fruit.—The fruits of Citrus have a rind or peel, which serves as a cover to the pulp or juicy part of the fruit. Viewing the parts more in detail, the rind is made up of a cuticle on the outside, thinly covering an epidermal layer of cells containing numerous oil vesicles. According to Tschirch and Oesterle (1895), the epidermal cells and subepidermal cells contain numerous cromatophores, green in young fruits and yellow in mature fruits; these cromatophores give the color to the fruits. A white spongy portion of parenchymatous cells (albedo) lies within the epidermis next to the pulp. The cells of this spongy layer are loosely arranged toward the inner portions; in this cell layer are also found many pockets containing oxalate crystals. Radially branching vascular bundles extend through this whole tissue of the fruit wall, especially the outer layer. The inner flesh of the fruit consists of compartments or segments (Figs. 154–156), the walls of which are of thin tissues of epidermal origin. From these walls small hair-like papillæ emerge, which become club-shaped and later turgid and closely compacted together and constitute the juice-containing vesicles of the ripe fruit. There are also yellow chromatophores of crystalline character in these vesicles. There is in fruit usually a central axis composed of spongy tissue. As in the leaves, there is a ramifying system of veins and veinlets through the segment walls to all parts of the fruit, containing the elements analogous to the cells of the cambium and conducting vessels of the wood and bark and connected therewith through the stem to the roots.

CHAPTER II

CLASSES AND TYPES OF CITRUS DISEASES; NATURE AND CLASSIFICATION OF FUNGI

CLASSES AND TYPES OF CITRUS DISEASES

The diseases of Citrus may be grouped in at least two ways: (1) as to their causes, and (2) as to the nature of the injury or effect. Viewed in relation to cause, Citrus diseases fall into approximately three groups with subdivisions as follows:

Diseases due to animal organisms, as

1. Small soil organisms, such as nematodes.
2. Insects.
3. Rodents and other higher animals.

Diseases due to vegetable organisms, as

4. Algæ.
5. Fungi, including the bacteria.
6. Parasitic flowering plants: dodder, mistletoe etc.

Diseases due to non-parasitic influences, as

7. Malnutrition: mottle leaf, exanthema.
8. Physical factors of the environment; frost injury, sunburn.
9. Inherent genetic defects and physiological derangements: albino, hollow core, etc.

Most of the Citrus diseases are found in three of these nine causal groupings, namely, those due to insects, fungi and malnutrition. Many diseases, however, are due not simply to one of these causal factors acting alone. Frequently, some non-parasitic influence is acting along with the so-called causal organism. A set of causal factors come into operation, of which the organism may be either a very necessary part or only a secondary or accelerating factor. In some cases two or more organisms may act in conjunction, or one may open up the way for the inroads of the other. Quite often a physical effect of the environment or malnutrition precedes the attack of the organism. There are, however, a few highly parasitic organisms on Citrus that initiate disease in perfectly sound tissue.

Viewed in relation to the nature of the injuries or effects, the principal Citrus diseases may be roughly grouped into about seven categories:

1. Diseases in which lesions are produced by the extensive death or progressive dying of tissues or parts of the plant, as mal di gomma, Armillaria root rot, pink disease, bark rot, wood rots and various fruit decays.

2. Diseases in which the death or necrosis of tissue is soon limited by a natural check, forming definite depressed spots, as black pit, black spot, brown spot, anthracnose spot and other lesions on fruit, leaves and twigs.

3. Diseases in which lesions are formed by the local injury or death of a few cells accompanied by alteration or changes in the tissue, as scab, canker, melanose, first stage of psorosis, leprosis, etc.

4. Diseases in which there is a stimulus leading to an extensive production of an abnormal kind or amount of tissue (hypertrophy), as knots, galls, witches'-broom, multiple buds, etc.

5. Diseases or effects in which there is a stimulus to abscission of blossoms, fruit or leaves before extensive death of tissue takes place, as in June drop of navel oranges, anthracnose, blossom blight of limes, Citrus blast, leaf drop and various defoliating effects.

6. Diseases or effects in which there is merely an internal physiological derangement or reaction without extensive death of the tissue, as internal decline and membranous stain of lemons and exanthema gum pockets.

7. Diseases in which there is a loss of color or vigor in growth without death of tissue, as chlorosis and foliocellosis.

Diseases vary in their nature much in accordance with the kind of tissues affected. Some diseases are strictly in the bark tissues, others affect the wood only. Some are confined to the superficial cells of the leaves or fruit and others break down all kinds of tissue. In Armillaria root rot both the bark and the wood are rotted; in Pythiacystis gummosis the entire bark and cambium are killed, but the wood is only slightly affected; in decorticosis and leprosis only the outer portion of the bark is killed, the inner portion and cambium remaining alive; in Citrus blast only the softer parenchymatous tissues of leaves and twigs are invaded by the organism; in internal decline the interior tissues of the fruit are affected; in melanose and red blotch only the epidermis and a few layers of tissue are involved; and in anthracnose, tear stains, russeting and oleocellosis the effects are still more superficial.

THE NATURE OF FUNGI

Since the diseases to be discussed in this book are to a large extent those in which fungi are involved, either directly or indirectly, the nature of these organisms will be briefly discussed.

The fungi belong to one of the lowest divisions of the plant kingdom and include many diverse forms, from those with simple individuals many times too small to be seen without the aid of a microscope, to large complex forms like the mushrooms and shelf fungi. They vary more in relative size and form than a strawberry and an orange tree, a radish and a redwood tree, in the higher plants. They are classified by means of microscopic characters which enable them to be placed in an orderly array into divisions, classes, subclasses, orders, suborders, genera and finally into species. Sometimes varieties and even strains are recognized.

Broadly considered, the fungi also include the bacteria, which have much in common with the simplest of the true fungi. Fungi differ from most other divisions of the plant kingdom by having no green matter or chlorophyll. The bacteria are all very small, and each is a simple organism composed of a single cell or life unit, while the true fungi are usually larger and often consist of several to thousands of life units or cells joined together to make a form more complex.

In bacteria these life units multiply by simply elongating and splitting in two (fission), while the fungi grow by budding or branching from the ends of previously formed cells and by the formation of specialized spores.

There are in the fungi, in common with all living forms both plant and animal, units of life known as the cell. The cell, as the center of all life's activities, is that unit from which all animal and plant structure is built up. Speaking generally, the cell may be thought of as a very minute microscopic mass of jelly-like substance surrounded by a membrane, and usually containing granules and a ball of denser jelly-like substance (nucleus) inside of the thinner jelly (cytoplasm). All structures of both plants and animals are either modified cells or collections of cells or secretions from them. Lengthened into a thread, the cells become nerves; drawn out in a cotton boll they become fibers; elongated in the stem or leaf they become conducting vessels (tracheæ and sieve tubes); elongated into cylinders and placed end to end they become fungus filaments; coalescing and intertwining they collect to form mushrooms.

Fungi Magnified 4000 Times.—If one's eyes were suddenly possessed with a power to magnify objects 4000 diameters the simpler fungi would appear in size and shape like peas, earthworms, hens' eggs, potato tubers or jelly-filled rubber tubes. The pea and earthworm sizes would be the bacteria, the hens'-egg and the potato-tuber sizes the simplest fungi. In these simpler forms one would see a clear, transparent mass of jelly surrounded by a membrane of tougher material. It would yield to pressure like a rubber ball filled with jelly, and upon release would resume its original shape. Such forms would be the Citrus canker, Citrus blast and black pit bacteria, two hundred ten billion of which could occupy the space of a small earthworm.

The hens'-egg-sized fungi would be the yeast cells and the sour or oöspora rot fungus. The cells of the latter in mass on the fruit would be seen as interwoven branched strings of jelly-filled cells joined end to end somewhat like sausages.

In other fungi one would see large branching forms, the tubes as large as a garden hose. The tubes (hyphæ) would be filled with granular jelly and closed at the ends of the branches, and would contain denser balls of jelly (nuclei) scattered along at frequent intervals. This would be the mycelium of Pythiacystis and Phytophthora in the group known as the Phycomycetes, which contain some of the most destructive fungi.

In more complex forms the jelly-filled branching tubes would have cross-partitions or disks (septa) dividing them into short or long segments. The tubes would be branched and rebranched many times and the branches would be crossing, recrossing and weaving in and out to form a mycelium like that of Penicillium, Botrytis or Alternaria.

In still higher forms in the groups known as Ascomycetes and Basidiomycetes these jelly-filled, divided and branching tubes, miles and miles of them, would be close-pressed, twisted, jointed, interwoven or coalesced to form the sclerotia of the cottony rot fungus, rhizomorphs of the Armillaria or a stroma of the Diplodia fungus.

The fungi with such dimensions would bring into view an orange tree 8 miles high with a trunk 1200 feet in diameter and a spread of branches of 5 or 6 miles. The fungi, like great ropes, would be found weaving in and out of the bark tissue, or over the 200-foot width of a leaf surface. In an orange fallen to the ground and rotting with blue mold, the jelly-filled fungus pipes would be seen boring 1-inch holes through the walls of the cigar-box-sized cells of the 1000-foot diameter orange. The blue-mold tubes would be seen piercing the jelly within, dissolving and using as food the contents and walls, branching out between the boxes and forming wads and tangled strands as they proceeded. From a surface of tangled, flexible, branching pipes would arise branched stalks 3 feet high with long chains of spores ⅔ inch in diameter.

If sound were magnified in proportion one would doubtless hear noises as of falling timbers, as of snapping chords, as of the gurgling and rushing of water and as of deafening explosions of gases that would set the earth in a tremor for miles around. Then the airplane-sized fruit flies would appear and deposit their 2-foot eggs in the decaying mass, and in a few days the hog-sized maggots would wallow in the débris and devour part of the putrid mass, which would finally be converted by the fishworm-sized bacteria into simple elements of the soil to help feed the 8-mile-high orange tree again.

How Fungi Live.—All fungi live on organic matter, *i.e.*, they are powerless, as a rule, to make food for themselves from the simple elements of the air, water and soil, as do green plants. While the green plants are the constructive agents, or the manufacturers of organic compounds from simple inorganic substances through the energy they get from the sun, the fungi and bacteria, in common with all animals, including man, are the destructive agents. The fungi tear down what green plants have built up. They feed on plants directly, or they feed on animals which have first devoured plants directly, or even in a more indirect way they feed on animals which have devoured other animals, which have eaten green plants directly. Fungi depend, therefore, as do animals, either directly or indirectly upon green plants, those which live upon live organisms being known as parasites and those which live on dead organic matter of any kind being known as saprophytes.

Most fungi are disseminated and kept alive mainly by means of spores. The form of the spores and the manner in which they are produced are more various than are the forms and the manner in which seeds are produced in flowering plants.

The jelly-filled divided tubes (hyphæ) may in some cases give rise at their ends or near their partitions to egg-shaped, sausage-shaped or disk-shaped bodies, filled with a denser jelly than the tubes which gave rise to them. These may stick together in chains or in heads, or in all sorts of ways, according to the species. They may in mushrooms be borne inside of minute pores or on radiating plates, the gills. These spores are produced in myriads. Buller has on conservative estimate found that a specimen of mushroom, something like the Armillaria root rot fungus, 3 inches in diameter, may produce 1,800,000,000 spores. A specimen of bracket fungus 7 inches in diameter produced 11,000,000,000 spores. He found that 2 square inches of a certain bracket fungus in the laboratory during one week shed three-quarters of a billion spores, and that during the first twelve hours an average of 9,000,000 were shed per hour.

In some fungi a more resistant form of spore is produced, as a result of sexual union. A tangle of jelly-filled fungus tubes begins to form special kinds of cells, with thicker walls, many glued together to form a hard, thick-walled hollow sphere (perithecium). Inside this sphere from a definite portion grow single-celled, jelly-filled, thin-walled sacks (asci), that project into the hollow space. Then the jelly inside these sacks or asci separates itself into distinct masses, thick walls form around the masses and they become spores. The spores are thus inside a sack (ascus), which itself, with other sacks, is inside a stronger, hollow, resistant sphere (perithecium), which, with other spheres, may be inside a tough, spongy, resistant tangle of jelly-filled tubes (stroma). These spores may be preserved for years, when on getting into favorable surroundings they may grow into jelly-filled tubes again to do many things both harmful and useful, according to the particular species to which they belong.

CLASSIFICATION OF FUNGI

The term "fungi" considered in its broad sense may be applied to three groups known as (1) Myxomycetes, slime molds; (2) Schizomycetes, bacteria or fission fungi; and (3) Eumycetes, or true fungi. This last group is divided into three natural classes: Phycomycetes, Ascomycetes and Basidiomycetes; and a fourth class, whose perfect stage is unknown, the Fungi Imperfecti.

The following outline is largely that of Gywnne-Vaughan (1922), with characterizations drawn largely from Butler (1918) and others, and with examples of the groups taken from Citrus fungi when known genera occur. For further details as to classification and description of fungi in general the student may refer also to "Die Natürlichen Pflanzenfamilien," by Engler and Prantl (1897-1900); "Genera of Fungi," by Clements (1909); "The Fungi Which Cause Plant Disease," by Stevens (1913); "Sylloge Fungorum," by Saccardo, and other special works.

GENERAL OUTLINE

MYXOMYCETES, slime molds.

SCHIZOMYCETES, fission fungi or bacteria. Pseudomonas, Bacterium.

EUMYCETES, true fungi:

I. **Phycomycetes:** lower fungi with non-septate hyphæ and alga-like sexual reproduction and asexual reproduction by means of sporangia.

A. Archimycetes: mycelium often rudimentary or obsolete.

B. Oömycetes: vegetative mycelium non-septate, sexual reproduction by a union of distinct male and female cells to form oöspores. Phytophthora, Pythiacystis, Pythium.

C. Zygomycetes: vegetative mycelium also generally non-septate, reproduction by means of the union of two similar cells to form zygospores. Rhizopus, Entomophthora.

II. **Ascomycetes:** sexual spores in asci or sacks, asexual spores may be conidia or oidia, mycelium septate.

A. Plectomycetes: asci formed directly on the mycelium or on special parts of it. Nematospora, Saccharomyces.

B. Discomycetes: asci usually formed on a cup-shaped body with incurved margins which often unfold into a disk-shaped, spore-bearing surface. Sclerotinia.

C. Pyrenomycetes: asci usually formed in a hollow sphere or flask-shaped body, the perithecia. Rosellinia, Glomerella, Botryosphæria, Pleospora.

III. **Basidiomycetes:** higher fungi with spores on basidia, which are cells resulting from a reduced form of sexual union; mycelium septate, frequently with clamp connections between hyphal cells.

A. Hemibasidiomycetes: smut fungi; no representatives on Citrus.

B. Protobasidiomycetes: rust fungi; no species on Citrus.

C. Autobasidiomycetes: hyphæ often uniting to form large conspicuous masses or special tissue-like structures exemplified in the mushrooms, puffballs and most of the larger fungi. Armillaria, Fomes, Schizophyllum, Corticium, Septobasidium, Polystictus, Stereum.

IV. **Fungi Imperfecti:** imperfect fungi known only in their asexual forms usually only with conidial spores, or rarely without spores.

A. Sphæropsidales: spores on short hyphæ inside of flask-shaped bodies known as pycnidia; spores not in asci. Phomopsis, Diplodia, Phoma, Phyllosticta, Septoria.

B. Melanconiaels: spores not in pycnidia but usually in cavities partly covered by the substratum, the resulting structures being called acervuli. Glœsporium, Colletotrichum, Sphaceloma.

C. Moniliales (Hyphomycetes): pycnidia and acervuli absent, spores on simple branches of the mycelium or on a complex branched coniophore. Penicillium, Aspergillus, Trichoderma, Oöspora, Fusarium, Ægerita, Verticillium, Cephalosporium.

D. Mycelium sterile: Sclerotium, Rhizoctonia.

Myxomycetes or Slime Molds

The vegetative stage in this group consists of naked protoplasm. Spores are formed in the final resting stage usually in sporangia. The best-known disease-producing form is *Plasmodiophora brassicæ*, causing club root of cabbage and other Cruciferæ in temperate countries. Many saprophytic forms of slime molds are found on rotting wood and decaying organic matter. This group is not represented by any Citrus-disease organisms.

Schizomycetes—Fission Fungi or Bacteria

Bacteria are minute one-celled organisms occurring in spherical, rod-shaped or spiral forms, often provided externally with protoplasmic, thread-like appendages (flagella) by which they move about in liquids. They reproduce by a process of dividing in two and usually splitting apart, known as fission. This group is represented in Citrus diseases by at least three known species, *Pseudomonas citri* of Citrus canker (Fig. 60), *P. citriputeale* of Citrus blast and *Bacillus citrimaculans* of the bacterial disease of South Africa (Fig. 164).

Eumycetes or True Fungi

Within this group, which includes the true fungi, most of the known organisms causing fungus diseases in Citrus are found. Some are beneficial parasites preying on Citrus insects, and thus aid in keeping them in control. The whole group comprises many thousands of described species, the great majority of which are harmless or beneficial saprophytes living on dead matter and aiding in breaking it down into simpler compounds. Three distinct natural classes are recognized. An appendix, known as Fungi Imperfecti, is usually added as a fourth class, to accommodate those which cannot be put into either of the other classes because of lack of known perfect spore stages or other definite identification marks.

Phycomycetes.—This lowest class of true fungi is often known as the alga-like fungi, because they resemble some groups of the green alga. Many of the aquatic fungi and simpler land forms belong to this class. The sexual reproduction is of a distinct and simple type, and the nuclei usually fuse in the cells in which they come together. Most of the species also have an asexual stage, which is usually more conspicuous than the other. The vegetative hyphæ do not unite in strands nor form a tissue, and usually remain without cross-partitions or septa except at the base of fruiting structures. The class is divided into three subclasses, Archimycetes, Oömycetes and Zygomycetes. In Archimycetes the mycelium is rudimentary or obsolete. The other two subclasses are represented by important Citrus fungi.

Oömycetes.—This subclass is distinguished by having sexual reproduction by female cells (oögonia), which are fertilized from male cells (antheridia) to form oöspores. One order, Peronosporales, contains many important plant parasites, among which on Citrus are *Pythiacystis citrophthora* (Figs. 21–23), *Phytophthora parasitica* (Figs. 27–29), causing rots and gum diseases, and Pythium, associated with damping off. This order reproduces sexually by an oöspore resulting from the union of protoplasm of an oögonium and antheridium and asexually chiefly by means of zoöspores formed in a sporangium.

Zygomycetes.—This sublcass is distinguished from the Oömycetes by having its sexual reproduction by means of the union of two similar or nearly similar cells, which result, after fusion, in a zygospore. The asexual fructification is not by means of zoöspores, as in the other subclass, but by non-motile spores in sporangia or on conidiophores. The first order, Mucorales, contains Mucor and Rhizopus, sometimes found on rotting Citrus fruits; and the second, Entomophthorales, contains species of Entomophthora found on Citrus insects. It also contains a species of Empusa seen on dead house flies on windowpanes, producing the well-known "frosted flies."

Ascomycetes.—There are over 15,000 described species in this class. The vegetative hyphæ have numerous cross-partitions or septa, and the sexual spores are produced in a mother cell known as the ascus, arising from special cells. The asci are usually borne within or on a special body, the ascocarp, formed by the union of a number of vegetative cells. The sexual reproduction is more obscure than in the Phycomycetes. A hollow sphere or flask-like body enclosing the asci is known as a perithecium, but a wide open receptacle is known as an apothecium or ascophore. These special bodies may in some forms be within or on a tissue-like structure formed from the coalescing and compacting of hyphæ and known as a stroma. In some forms also there are compact aggregations of hyphæ, known as sclerotia, which are very resistant to drying out. In addition to sexual spores there may be asexual forms, as described in the Fungi Imperfecti. The three subclasses all contain important Citrus-disease fungi.

Plectomycetes.—This subclass contains species in which the asci are formed directly on the mycelium or on special parts of it, and usually not on complex ascocarps, as in some of the other orders. In Citrus it is represented by the inspissosis or dry rot fungus, Nematospora (Fig. 148), and probably by certain Saccharomyces or yeasts which appear to take part in the soft rotting of fruits. Some of the species of Penicillium and Aspergillus have perfect stages which place them in this subclass.

Discomycetes.—The asci are formed on an ascocarp, which is usually cup-shaped with incurved margins unfolding as it matures, exposing the ascus-bearing surface. The well-known cottony rot fungus, *Sclerotinia libertiana* (Figs. 126–127), belongs here.

Pyrenomycetes.—The asci in this order are usually formed within a flask-shaped body known as the perithecium, with a narrow mouth (ostiole) through which the spores escape. Asexual stages with more delicate spores borne not in an ascus, but on the ends of free hyphæ, are also common. This is a very large subclass with numerous genera and species. Important Citrus genera are Glomerella, Rosellinia (Figs. 8, 9), Botryosphæria (Fig. 144), Physalospora and Pleospora. Many forms which probably belong in this order are known on Citrus only in their imperfect stages, and are usually classified in the Fungi Imperfecti.

Basidiomycetes.—This third main class of the true fungi includes a large number of known higher fungi, most of the so-called mushrooms or toadstool forms, as well as the smut and rust fungi. They are very diverse in size and form but include many of the larger definite forms whose sporophores may be readily seen without the aid of a microscope. The Basidiomycetes have no asci and only a very reduced form of sexual reproduction. Special spore-bearing cells (basidia), usually club-shaped, arise, from which there project two or four minute short stalks (sterigmata), each bearing a one-celled spore. This class is divided into three subclasses, Hemibasidiomycetes, or smut fungi; Protobasidiomycetes, which include the rust fungi; and Autobasidiomycetes, which include the mushrooms, puff balls and most of the larger fungi.

Hemibasidiomycetes or Smut Fungi.—The members of this subclass are all plant parasites. About 400 species are known, of which none are represented in Citrus fungi. The mature spores usually form a dense black mass. The vegetative mycelium is filamentous, and no compact tissue is formed except in the spore beds.

Protobasidiomycetes.—This subclass includes the rust fungi, of which there are over 17,000 species, all obligate plant parasites. Not a single one, however, is known to attack species of Citrus. The mycelium of the rust ramifies the tissue of the host plant, and usually causes malformation of the affected parts. A majority of the mature spore masses are powdery and rust-colored.

Autobasidiomycetes.—This subclass has, in the mushrooms, puffballs and larger fungi, a tissue-like structure made up of interwoven strands of hyphæ. The hyphæ are often recognized by the presence of the clamp connections. The special cells or basidia are usually joined together side by side in a layer. On the end of each basidium are borne four spores on short stalks or sterigmata. *Armillaria mellea* (Fig. 4), causing a root rot of Citrus, belongs in this group. Other fungi of this subclass causing wood rots of Citrus are *Schizophyllum commune*, species of Fomes, Stereum, Polystictus (Figs. 54, 55), etc.

Fungi Imperfecti.—This is largely an artificially arranged class of fungi appended for convenience in order to classify fungi that have either lost some of the characters that would place them in the other three natural classes or whose life histories are yet too imperfectly known to enable them to be placed elsewhere. A large number of them are probably imperfect stages of Ascomycetes, fewer are stages of the Basidiomycetes and possibly a very few are imperfect stages of Phycomycetes. This class is largely in the nature of a useful set of files or pigeonholes for a miscellaneous lot of organisms that do not yield to the more natural system of classification. Those classified here are devoid of known sexual reproduction or sporangium formation. The reproduction is usually by means of conidial spores. Three subclasses have been formed based on the manner in which the spores are formed, or the manner in which they are arranged on the hyphæ or within special receptacles. These are again subdivided into families and then into genera by an artificial method based on the color, shape and divisions of the spores. Many Citrus-disease fungi are included here.

Sphæropsidales.—The spores in this order are produced within spherical or flask-shaped fruiting bodies (pycnidia) and are formed on the ends of short stalks that project inward from the pycnidial wall (Fig. 139). The pycnidia usually open by a small pore or slit allowing the mature spores to escape. In Citrus the order is represented by important organisms, such as the species of Phomopsis (Figs. 138–140), causing melanose and stem-end rots, *Diplodia natalensis* (Fig. 143) and other Diplodias, *Phoma citricarpa* (Fig. 180), *Septoria citri*, Phyllosticta and others.

Melanconiales.—The spores in this order are produced not in a pycnidium but in an immersed cavity of which the outer wall is usually formed by the tissues of the plant or by other enveloping substances. Such a fructification is known as an acervulus. This order is represented in Citrus by the anthracnose fungi Glœosporium and Colletotrichum (Figs. 88, 89, 170), some of which are known to have perfect stages as Ascomycetes.

Moniliales (*Hyphomycetes*).—The spores may arise from simple, free branches of the mycelium or from erect bundles of hyphæ or even from superficial cushions of hyphæ. The diverse forms in this order range from those in which the hyphæ merely divide into spores to those with specialized conidiophores with a complex system of branches. It contains a large number of genera. Citrus fungi are represented in this order by a number of fruit-decay fungi, *Oöspora citri-aurantii* (Fig. 120), *Trichoderma lignorum* (Fig. 115), *Aspergillus niger* (Fig. 117), *Penicillium italicum* (Fig. 113), *P. digitatum* (Fig. 111), *P. roseum* (Fig. 114) and *Botrytis cinerea* (Fig. 128) and by species of Fusarium. Among the fungi on Citrus insects are Isaria, Ægerita, Verticillium and Cephalosporium.

Mycelium Sterile.—After all forms of fungi with spores are classified there are some which persist in living by means of mycelia without forming spores, so these are placed together in a subappendix under the Fungi Imperfecti. *Sclerotium rolfsii* (Fig. 119) is one of these. It forms small spherical bodies or sclerotia which serve in place of spores. Another is the damping-off fungus, Rhiozctonia.

CHAPTER III

GEOGRAPHICAL DISTRIBUTION OF CITRUS DISEASES

Some Citrus diseases are world wide in their distribution, mal di gomma or similar types of gum diseases may be cited as good examples, since they have been reported in almost every country where Citrus is grown. Other Citrus diseases are apparently restricted to a single country or a part of it. The bacterial spot of South Africa is a good example, since it appears to be restricted to the western provinces of the Union of South Africa.

Some Citrus diseases which appear to have had an opportunity to become well distributed in all countries where Citrus is grown are never the less limited—by climatic conditions, moisture, temperature or other environmental conditions—to certain countries. In some cases it is apparently a lack of one or more factors in a set of conditions that limits their distribution. An example of this is verrucosis or scab, which, because of the susceptibility of the sour orange, is thought to have had ample opportunity of spreading to almost every country of the world. It is known to have been shipped into California on sour orange trees many times, but it never persisted there. A disease may be more prominent in a given country because the most important commercial varieties grown there may be susceptible to that particular disease and not to others. In certain root and trunk diseases the particular kind of rootstocks used may have a large determining influence on their occurrence, as, for example, mal di gomma, Pythiacystis gummosis and some of the root rots. In certain other cases, however, the absence of a disease is due to the fact that it has not yet been introduced or that it has been eradicated. A striking example of the latter is the Citrus canker, which at one time was established in Florida and South Africa, but which as far as now known has been eliminated from these two localities.

The main areas in the world in which Citrus growing is commercially important are: (1) California; (2) Florida, the Gulf states, Mexico and the West Indies; (3) the Mediterranean countries, with Italy, Spain, Palestine, Egypt and certain parts of northern Africa as the main localities; (4) South Africa; (5) Australia; (6) China; (7) Japan; (8) the Philippines and East Indies; (9) India; and (10) South America with Brazil, Paraguay and Argentina as the main localities.

California.—The most important orchard diseases in California appear to be Pythiacystis gummosis, with the accompanying disease of the fruit known as brown rot, psorosis, shell bark, mottle leaf and, locally, Armillaria root rot and Citrus blast. Citrus blast is usually only important to the northern Citrus sections near the foothills. During certain seasons or in limited localities other diseases may sometimes assume major importance, such as anthracnose, Botrytis gummosis, internal decline, Alternaria rot of lemons, black rot of oranges, June drop, etc. Probably the most widely distributed bark diseases on oranges are psorosis and Pythiacystis gummosis and on lemons Pythiacystis gummosis and shell bark. A large list of special fruit rots also occur.

Florida, Gulf States and West Indies.—The diseases which are of major importance in Florida are almost entirely different from those in California. This fact is most striking, and is thought to be due largely to the differences in climatic conditions. In the early days of the industry considerable interchange of trees took place between Florida and California, so that probably the trees in each locality had an opportunity to become exposed to all the diseases that existed in the other, with the exception of some of the diseases which originated after a strict quarantine was established. Those of most importance in Florida are perhaps melanose with the accompanying fruit rot known as Phomopsis stem-end rot, scab, exanthema, mal di gomma and perhaps anthracnose. Locally or on particular varieties there occur psorosis, leprosis or nailhead rust, blight, Diplodia gummosis, etc. It is seen that none of the diseases that appear to be of major importance in California are of major importance in Florida. Some of those that are of major importance in one state may be of minor importance in the other, and *vice versa*. The Citrus canker, at one time very important in Florida, has apparently been eradicated.

In the other states bordering the Gulf of Mexico the Satsuma orange budded on the trifoliate-orange rootstock is the principal variety. The main diseases of the Satsuma orange appear to be scab and melanose, with psorosis as a minor trouble at the present time. Since the trifoliate-orange stock is resistant to mal di gomma, this disease is not a major one with that variety. Citrus canker in localities where it is not yet eradicated is also an important disease.

In Cuba some of the major diseases are the same as those in Florida, such, for example, as mal di gomma, scab and anthracnose of the lime. Diplodia gummosis, especially on grapefruit, is of more importance in Cuba than in Florida. Other important Florida diseases, such as exanthema and psorosis, appear to be of minor importance in Cuba, and melanose and blight are of rare occurrence, and canker has never been reported.

In Porto Rico and other West Indian islands the diseases of major importance appear to be mal di gomma, scab, Diplodia stem-end rot and anthracnose of lime.

Mediterranean Countries.—In the countries bordering the Mediterranean one of the most important diseases, in the past at least, has been a trunk and root trouble similar to mal di gomma or Pythiacystis gummosis. In the years between 1863 and 1870, according to Savastano, this disease did great damage in many countries. It was especially severe in Sicily, where it destroyed most of the trees. The new orchards which have since been planted are on sour-orange stock budded high above the surface of the soil. Other diseases of considerable importance are root rots and citro-necrosis ("mal secco"). Psorosis on the orange, shell bark on the lemon, anthracnose and others are also present. Scab, canker and leprosis have not been reported from the Mediterranean countries.

In Palestine by far the most important disease is a bark disease resembling Pythiacystis gummosis or mal di gomma as reported to us recently by a representative Citrus grower from that country. The majority of the Citrus trees grown in Palestine is the Jaffa orange budded on the sweet-lemon root. In the past these were budded low and in many cases the bud union became buried below the surface of the soil. In the last six years it is reported that nearly 20 per cent of the trees in some localities have been killed by gummosis. Irrigation had been carried on until recently by flooding, with the tree in the middle of the space, thus allowing the water to stand around the trunk. Recently a change in the method of irrigation, so that the soil is not kept wet around the trunks, but only between them, has greatly checked the progress of this disease.

In Egypt[1] also the disease of greatest importance is that of Pythiacystis gummosis. The principal rootstock is the citron, which is very susceptible to this disease. T. Fahmy states that mal di gomma, melanose, exanthema and chocolate spot have been observed in Egypt. Melanose occurs on neglected mandarin trees. Chocolate spot which is being reported for the first time by T. Fahmy (p. 276) Chap. XIII appears to be a new disease of the orange fruits and leaves.

South Africa.[2]—One of the most widespread diseases, especially on heavy soils, is mal di gomma ("collar rot"). Scab is common in nurseries in the humid districts, but is a negligible disease in the orchards. Two types of partial chlorosis, mottle leaf and the ring blotch, anthracnose, Alternaria rot, bacterial spot and Diplodia rot are also of considerable importance in certain districts. Citrus canker which was at one time introduced into South Africa is now reported to have been eradicated. Doidge (Davis 1924) reports that psorosis, which has appeared in recent years, about 1919, is likely to prove one of the most serious diseases. Brown rot due to *Pythiacystis citrophthora* has quite recently been noted by E. Doidge (1925). An effect similar to melanose has also been found in one locality on the east coast.

---

[1] We are indebted to T. Fahmy for information regarding the diseases in Egypt.

[2] To E. M. Doidge we are indebted for information on South African diseases.

Australia.[1]—Probably one of the most important and widely distributed diseases, especially in moist climates or localities in Australia, is mal di gomma ("collar rot"). Others are leaf blight and fruit rot, formerly thought to be due to *P. citrophthora*, but recently found, by W. M. Carne (1924), to be due in western Australia to a different but related fungus, a species of the genus Phytophthora.

In New South Wales the black spot due to *Phoma citricarpa* attacks most varieties of oranges, disfiguring the skin. Anthracnose or brown spot of the Emperor mandarin often causes a heavy fall of fruit when it is partly grown and also kills back twigs. Exanthema is troublesome on sandy soils lacking in humus, especially if the subsoil is poor. Armillaria root rot also causes damage in some districts, and scab may do much damage to lemons in other localities.

In Victoria the disease similar to the brown rot of California, probably due to a Phytophthora, is troublesome, especially after heavy rains and cold weather. Mal di gomma ("collar rot") occurs in irrigated areas. Botrytis may also injure the twigs and branches on young lemon trees.

In South Australia the disease similar to brown rot appears to be the most injurious.

In Western Australia one of the most severe diseases also appears to be the disease similar to the brown rot, and causes much damage to leaves and fruit and is probably due, as in these other places, to a species of Phytophthora.

In New Zealand also the disease similar to the brown rot is troublesome, as are scab, melanose, mal di gomma, black spot and sometimes Armillaria and Botrytis twig blight.

Citrus canker was at one time found in a locality in the northern part of Australia, but has been dealt with by eradication measures.

China.—China is probably the oldest Citrus-producing country in the world, but possibly with few exceptions the industry is at the same stage of advancement as it was several centuries ago. A number of Citrus diseases of major importance occur which greatly lessen yields and qualities of the fruits. The Citrus industry of China probably suffers more losses from diseases than that of any other counry, with the possible exception of some of the East Indies.

Undoubtedly, the most devastating disease is psorosis, which is almost universally distributed and greatly limits the age of orchards. The susceptible sweet orange, which is widely grown in China, becomes affected when but five or six years old. Orchards are often decimated in numbers when ten years old and a twelve-year-old orchard is a rarity. Next to psorosis, mal di gomma causes great destruction.

---

[1] For information about the principal diseases of Citrus in the various parts of Australia we are indebted to G. P. Darnell-Smith, G. H. Cunningham, K. M. Curtis, G. Samuels, C. C. Brittlebank and W. M. Carne.

Except in a few localities, orchards are planted with seedling trees not grafted or budded. Sweet oranges then, with sweet-orange trunks and roots, are very commonly affected and destroyed by foot rot or mal di gomma. Bark rot is almost equally destructive in the extensive plantings of mandarin orange trees.

Citrus canker is widespread and is believed by some to have originated in China. The very susceptible grapefruit and lime varieties, however, are not grown and consequently the disease is not very destructive. Sweet-orange fruits are very commonly blemished by Citrus-canker lesions, and a few fruits may be dropped because of the presence of the disease, but in China the disease does not destroy the branches or entire trees as does psorosis and mal di gomma. Mandarin oranges which are probably planted more widely than sweet oranges are apparently not affected by Citrus canker in China. Scab occurs in China on a number of varieties. Black spot, caused by the fungus *Phoma citricarpa*, is of general occurrence as a fruit blemish on both mandarin oranges and sweet oranges, and probably causes as much or more loss than either Citrus canker or scab.

The handling of fruit in China is very primitive; there seems to be little knowledge of the relationship between injuries and decay, and no attention is paid to fruit disinfection or to ventilation. Various kinds of decay, such as the green and blue molds, a Diplodia rot and others, cause enormous losses year after year.

Japan.—The industry in Japan is much more advanced than in China and the handling of fruits is well organized and to some extent supervised by the government. Nevertheless, there are large storage losses due to blue and green molds, hyaline rot and doubtless other rots. There are storage houses in which the value of ventilation is utilized and the careful handling of fruits to avoid bruising is understood by even the lowest-paid orchard laborers. Nevertheless, fruit rots, as a whole, probably cause greater losses than any one disease in Japan. Next to storage losses, mal di gomma probably causes the greatest injury, although psorosis sometimes destroys sweet orange and bark rot, Satsuma orange trees. The Satsuma orange is the most extensively planted Citrus fruit and, since it is very susceptible to scab, losses from this disease are often of major importance. Scab is often well controlled in Japan at the present time by applications of Bordeaux mixture. Citrus canker is of general occurrence on the trifoliate orange, *Poncirus* (*Citrus*) *trifoliata*, which is widely planted as hedges, but since the Satsuma oranges are resistant there is little economic loss from canker. Washington Navel oranges sometimes lose a little leaf area and suffer from fruit drop and a serious fruit blemish due to Citrus canker. Leaf drop, ascribed to a fungus of the genus Phyllosticta, occurs in a few districts and, while it is not widespread, it would seem to have serious potentialities under some climatic conditions differing from those of Japan. Pink disease is destructive in Formosa.

The Philippines and East Indies.—Citrus growing in the East Indies has been largely a matter of dooryard planting with only a few plantings, from 1 to 5 acres, which could be called orchards. Losses from diseases have been severe. In the Philippines psorosis and bark rot have caused the greatest losses. Mal di gomma is of general occurrence and is of almost equal importance. Scab has not yet been observed in the Philippines or Borneo, although it has been observed on limes in Java.[1] Pink disease is sometimes very destructive. Citrus canker occurs in most of the East Indies on limes and sweet oranges, but does not under the conditions there cause the destruction which the limb and trunk diseases do. The flowering parasites of the genus Loranthus often cause tangible decrease in the production of Citrus trees. Mildew occurs in Java, causing injury to mandarin orange trees. Losses from fruit rots are very severe.

India.—Little is definitely known of Citrus diseases in India. Anthracnose and pink disease are definitely recorded as well as the flowering branch and twig parasites of the genus Loranthus. A root and trunk disease reported to be due also to the fungus *Ustilina zonata* which is closely related to Rosellinia is reported as one of the important Citrus diseases of India. There are reports which indicate that mal di gomma occurs and reports which would indicate that both scab and canker are present. Mildew on the leaves and twigs of some varieties is very severe in Ceylon.

South America.—In Brazil, P. H. Rolfs reports that mal di gomma is quite general, as is melanose and stem-end rot. Anthracnose is found especially on leaves and exanthema, scab, fly-speck fungus and alga spot are also present. Psorosis on oranges and Botrytis gummosis on lemons are reported as common by L. E. Toledo, who had become familiar with these diseases in California.

In Paraguay, Spegazzini (1921) refers especially to mal di gomma, scab, lepra explosiva and a type of root rot. Scab appears to have been recently introduced into Paraguay.

In Argentina, forms of bark disease, such as mal di gomma and other gum diseases, appear to be the principal troubles as reported by G. L. Fawcett (1920). Scab has also recently appeared, having been introduced into one locality about 1918, and spread from that place as a center. Anthracnose of the leaf appears to be a disease of minor importance there.

---

[1] Our attention has been called since this was written to the fact that most varieties of limes are considered to be immune to scab (Winston, Bowman and Bach, 1925). The question arises as to whether the observed lesions in Java may not have been lime anthracnose, the lesions of which on young fruit is quite similar in general appearance to scab.

CHAPTER IV

CONDITIONS AFFECTING SEVERITY AND DISTRIBUTION OF CITRUS DISEASES

It is a matter of common observation, from the time of the earliest records, that weather and other environmental conditions have an important influence upon the severity of certain plant diseases.

So dependent are some diseases on the influences of the environment that before the causal parasites were known the diseases were usually attributed to weather or other conditions. In earlier times these environmental conditions were often personified by an evil spirit, as in King Lear, where Shakespeare refers to the "Walking fire, the foul fiend Flibbertigibbet who mildews the white wheat and kills the poor creatures of earth." Many uninformed people still think of parasitic plant diseases as being due to weather conditions alone.

For some Citrus diseases this view seems logical for all practical purposes, so closely dependent are the parasites upon some special or striking or unusual condition of the environment. The average environment in such a case may be likened to a woven wire fence around a lettuce field outside of which rabbits are always present. A break in the fence would inevitably result in destruction of the plants by the rabbits, and if the rabbits were invisible microscopic organisms, a logical explanation would seem to be that the plants were destroyed by a break in the fence.

In the cause for any condition which we designate as a fungus disease there are, in addition to the parasite and the internal conditions of the host, many contributing factors and influences of the environment, physical, chemical or biological. The fungus as well as the host is dependent on a set of conditions. While in some diseases the factors most favorable for the growth of the host may also be those for the best growth of the parasite, in others the factors unfavorable for the growth of the host may be those which are favorable for the fungus, or *vice versa.* These may enable the fungus to get a foothold by breaking down the resistance of the host. While a few fungi are highly parasitic, others are weak parasites or, as it were, "opportunists." They live most of the time on dead parts of the plant as harmless saprophytes, but when the right set of conditions arises they are able to act as actual disease-producing agents. Alternaria is a good example. These conditions favorable for the disease may be seasonal or may appear intermittently and in an irregular fashion. The young new growth may be the only part susceptible during a short period, as in the scab fungus, or the anthracnose fungus of limes. This period having passed, the tissue is immune to further attack. In other cases only the mature tissue is highly susceptible, as in some of the fruit rots.

A brief analysis of some of the effective environmental factors influencing plant diseases may be useful. Perhaps the most important factors are those represented by temperature, water relations, mechanical and chemical forces, with interacting combinations of these.

Temperature has an influence on diseases in many ways: (1) in its degree and duration within the ordinary range for the growth of parasite and host; (2) in its fluctuations, as, for example, chilling of the host followed by favorable temperatures, or rate of change from one extreme to another; (3) in its destructive extremes, as partial freezing and burning of the host or actual destruction of the parasite.

Water relations in all sorts of fluctuating combinations with temperature have a very important influence. There are the variations of air humidity, of soil moisture, of free moisture; there is the presence of droplets of dew, the influence of rain, of desiccation and so forth.

The mechanical forces of wind, hail, insects and higher animals have also a great influence, and the variations and fluctuations in the chemical forces of soil are not to be overlooked.

When one considers that under natural outdoor conditions all of these factors may be in a state of fluctuation, each with different time elements and different rates of change, the analysis and investigation of any given case become extremely complicated. A few examples out of many may serve to illustrate the foregoing statements.

In 1915 attention was called to a special combination of weather and other conditions in Orange County, California, which made a certain disease of orange fruit very destructive. These conditions have not occurred since. During April and the first five days of May, the sun was almost continuously obscured by clouds. Eleven out of the last fifteen days of this period were rainy, and the temperature was moderate, with a mean of 55.4°F. (13°C). Many of the moist petals, in falling, lodged upon or stuck to the Valencia-orange crop of the previous year, which was still on the tree. In these fallen moist petals was growing the fungus *Botrytis cinerea.* The constant moisture and moderately low temperatures were favorable for its development. The rind was softened and the fruit destroyed wherever the petals touched the rind. Here there were: (1) the factor of temperature; (2) of moisture; (3) of sufficient duration of the first two factors without the drying effect of sunshine; (4) the presence of falling petals; (5) the presence of a previous crop; and (6) that of a parasitic fungus. If any one of these six factors had been slightly different, or absent, the oranges would not have been destroyed in this way. This situation may not occur again in fifty years.

As the result of an investigation of Citrus scab (Fawcett 1921*b*) it was concluded that weather conditions had a profound influence on the severity of the disease in any given season. A study of the temperature relations revealed that infection, even under the most ideal condition of humidity was confined to the short range of between 60.8 to 73.4°F. (16 to 23°C.) of maintained temperature. This appeared to account for certain observations that scab is frequently absent at high summer temperatures in Florida even in the presence of sufficient humidity.

It has been further pointed out by Winston (1923) that, where temperature is not a limiting factor, humidity may be the limiting condition for the occurrence of scab under Florida conditions.

A study of the comparative temperature relations of the Pythiacystis gummosis fungus, *Pythiacystis citrophthora*, and the mal di gomma fungus, *Phytophthora parasitica*, showed that the former had a much lower range for an optimum sustained growth and spore production than the latter (Fawcett 1921*a*). This is thought to fit in with the fact that the rainy season in California, when natural infection is most common for Pythiacystis, is during the cooler weather of winter and spring; while the moist season most suitable for *Phytophthora parasitica* infection in Florida usually occurs in the warmer weather of summer. We have here an interesting combination of temperature and water conditions, the two fungi varying in their temperature relations in a manner to suit the time of year when water is most abundant in the two localities. It has been found by Peltier (1920) that environmental conditions play an important part in the susceptibility of Citrus plants to canker. Three conditions are essential for infection: the presence of free moisture on the plant simultaneously with a suitable temperature and an actively growing tissue. Any slight variation from certain prescribed limits in either one of these three factors apparently prevents development of the disease, even though the organism may be abundantly present.

Citrus blast (Fawcett, Horne and Camp 1923) also depends on a rather special set of environmental conditions. This disease affects the petiole and an adjacent spot on the twig. The organism depends for its entrance on fresh injuries, usually slight breaks in the wings of the petiole, generally occasioned by winds. Other conditions of temperature and moisture must also be favorable at the time of breakage. There must be wind or other breakage accompanied and followed by cloudy weather with rain or heavy dews, over a considerable number of days. This brings in again the factor of duration of any given condition as well as its degree. Previous chilling of the tree, near to the frost point, even though no injury to the host is experienced, also appears to be a contributing condition. This special set of conditions is usually experienced in Butte County, California, near Oroville, in January, February and March. At this time temperatures may frequently occur which fluctuate between 40°F. (4.4°C.) or less, as a minimum, and 65 to 70°F. (18.3 to 21.1°C.) or lower as a maximum, with a predominance of cloudy days, and with frequent showers accompanied or followed by strong winds (p. 301). In southern California, although the organism is present, as shown by one of its manifestations on the fruit (black pit), the twig lesions seldom develop there because of the lack of certain of these factors, most probably those of cloudiness and moisture in sufficient, continuous duration. On the slopes of Mt. Wilson, however, in 1922, the right conditions prevailed, namely, 30 inches of rain from January to April, with wind, cloudiness and low temperatures, and blast lesions developed there in the same manner as in northern California. Blast was also noted at Acireale, Sicily, as most prevalent on the sides of trees facing the ocean.

By imitating, in a cloth cage, the natural conditions favorable to blast (Camp 1921), with trees constantly subjected to a water mist from a spray nozzle and with favorable temperatures, typical lesions on leaves and twigs were readily produced. Inoculations made under other conditions failed. In Citrus blast, therefore, we have exemplified also, a disease dependent on a very special set of environmental conditions involving phases of temperature, water, mechanical forces and probably a physiological condition of the host brought about by chilling.

Many other examples could be mentioned of how the direct or indirect relation of moisture, temperature, wind, chemical and physical forces of the environment, or combinations of the two or more of these conditions, profoundly influence the severity and distribution of Citrus diseases.

Combined Effects of Different Organisms.—It has been a common observation that two or more parasitic or semiparasitic organisms may be associated in the same lesions and it is reasonable to assume that in many cases the disease is aggravated or made more severe by two or more organisms acting together than when each is acting alone. The reverse, however, may sometimes take place, by which one organism makes conditions less favorable for the other.

Experiments with Citrus fungi by Fawcett (1913*a*) indicate that certain fungi introduced simultaneously by inoculation into Citrus trees may produce much more damage than when each is introduced alone. Inoculations combining two or more of the four fungi commonly found in Florida (Diplodia gummosis fungus, *Diplodia natalensis;* anthracnose fungus, *Collectotrichum glœosporioides;* stem-end rot fungus, *Phomopsis citri;* and *Cladosporium herbarium* var. *citricolum*) in various ways showed that certain associations could become very severe in killing tissue. The inoculations were made by introducing bits of mycelium into small cuts on healthy orange trunks about 2 inches in diameter. Combined effects of *D. natalensis* and *C. glœosporioides,* also of *D. natalensis Ph. citri* and *Cl. herbarium* var. *citricolum* were capable of killing the trees in two to four weeks, an effect much more severe than inoculations with any one of these organisms alone had produced in other experiments.

Inoculations with *Pythiacystis citrophthora* combined with Fusarium sp. in California indicated that the lesions of Pythiacystis gummosis became larger and the disease progressed faster and became more severe than when *P. citrophthora* was inoculated alone (see Pythiacystis Gummosis, p. 138). It has been repeatedly observed that species of Fusarium are commonly associated with severe cases of Pythiacystis gummosis.

Further investigations will probably show that many different cases of combined effects occur in connection with Citrus diseases. With certain diseases where the organisms are only semiparasitic or of a secondary nature, this is probably the rule rather than the exception. In others in which the organism is more parasitic and attacks young vigorous tissue, it is probable that one organism acts more often alone, in its initial invasion of the tissue. This injured tissue, however, is often entered later by organisms not capable of attacking young growth, but having once gained entrance to dead cells it is capable of advancing into the maturing tissue. There appears to be in certain cases a succession of organisms, one preparing the way for the work of the others. An example is furnished in the heart rot or wood rot following frost in California. A species of Diplodia first enters and darkens the wood, and later this is invaded by *Schizophyllum commune, Polystictus versicolor, Stereum sp.,* etc. Many examples occur in fruit rots where one organism is associated with or follows the invasion of another.

That one organism may hinder the attack of the other when both are introduced together was found in some unpublished experiments of Fawcett with the Melaxuma fungus, *Dothiorella gregaria,* and the walnut blight bacterium, *Pseudomonas juglandis.* The *D. gregaria* alone was capable of producing large lesions on walnut branches, often girdling and killing them. Inoculations of the same kind in which *P. juglandis* was mixed with the fungus mycelium of *D. gregaria* failed to produce lesions or any appreciable injury.

CHAPTER V

GENERAL PRINCIPLES OF PREVENTION AND TREATMENT OF CITRUS DISEASES

In combating plant diseases the most desirable and usually the least expensive means lie in the line of prevention rather than in that of treatment after the disease has started. In the control of certain Citrus diseases preventive methods are the only means that can be successfully employed, in certain others, preventive and curative methods go hand in hand, while in still other diseases the curative methods are the principal means available, with our present imperfect knowledge of their nature and cause.

In the practical prevention and treatment of diseases two things must always be considered: (1) effectiveness of the methods, and (2) expense of the treatments. It is obvious that means of control must be employed that are considerably less costly than the losses caused by the disease.

In diseases due to parasitic or semi-parasitic organisms, prevention may be brought about by various means often depending on the nature of the disease itself. Some of these which may be mentioned are: (1) keeping down sources of infection; (2) avoiding the contributing conditions for infection and the development of disease even when the organism is present; (3) covering the susceptible parts of the tree with fungicides or disinfectants to prevent the entrance of the organisms; (4) employment of resistant species or varieties; and (5) exclusion of the parasitic organism from entrance into the particular orchard or section, or even from entrance into the particular country where it has not already become established.

The curative means employed for diseases due to parasitic organisms consists for the most part in eliminating the diseased parts of the tissue that has already become invaded or weakened by the organism. In treatments of this kind, measures are also usually undertaken at the same time to prevent infection and spread of the same disease to other parts of the same tree or to other trees in the same orchard. Curative and preventive methods here go hand in hand. Where serious diseases have started to develop in a certain locality or section the principle of prevention often consists of the entire destruction of all trees that have even a trace of the disease, thus preventing it from spreading throughout the particular country or section. This method has been employed successfully in combating the Citrus canker in Florida and in South Africa.

The principle of resistance may also be applied. In fungus diseases, for example, there is, in a sense, a fight or reaction between two kinds of plants, the fungus plant and the tree plant. The resistance of healthy and vigorous trees against certain diseases is often very great. Conditions surrounding both the tree and the fungus may largely determine whether the tree can sufficiently resist or escape the attack or whether the parasites may become established in sufficient numbers to injure the tree materially. With certain Citrus parasites, moreover, the tissues of the tree are vulnerable only at certain periods in their development, as with scab and melanose. The immature newer growth is susceptible, but the mature growth is immune. There is, therefore, a comparatively short period when the way is open for attack of the parasite. This explains why some fungus diseases may vary so in severity during certain periods and why the disease is often attributed entirely to weather conditions, when, in fact, it is due to the attack of some microscopic organism which is favored in its growth and development by a particular condition of the tissue and the weather.

In diseases that have for their cause nutritional disturbance or the effects of environmental conditions, prevention consists in employing means to avoid these conditions when they tend to bring on such disturbances. Curative methods with these diseases may consist both in the reestablishment of conditions that will allow the tree to recover when new growth takes place, or in elimination of parts of the tree by pruning. As in the other case, preventive methods are more desirable and usually much less expensive than curative means.

Orchard Sanitation.—Proper sanitation in the orchard is often effective in preventing diseases from becoming serious. This may consist in keeping down sources of infection and in bringing about favorable conditions for the growth of the trees, so that they will be resistant.

Very common possible sources of infection often exist in the dead parts of the tree itself. Some of the disease-producing organisms live and propagate in the dead or functionless tissues. Dead twigs, branches and decaying wood may be sources for the propagation and multiplication of the organisms. For example, an important source of infection for melanose and stem-end rot exists in dead twigs and branches. Some organisms, such as Botrytis and Sclerotinia, may first become established on dead tissue weakened by frost or other causes and, having become well established, may advance and invade the sound tissue, producing much damage to the tree. In other cases, old or functionless bark tissue may first harbor certain organisms and be a means of increasing the supply of spores or infectious material. Large stubs left in pruning and wounds may provide dead tissue into which organisms may enter and become established, as, for example, the wood rots due to *Schizophyllum commune* and *Polystictus versicolor*. It is therefore important, especially in moist climates, that dead branches and twigs be pruned out as far as economically possible. When these are known to be sources of infection it is best to burn them. In dry climates this source of infection is not so important, although there is often a moist, damp period of the year during which organisms may readily develop in these dead parts. In pruning out limbs, those with cuts more than an inch in diameter should usually be disinfected and painted later, or painted with something that may be both a disinfectant and a covering. The cut should be made smooth and close to the branch, so as not to leave a projecting stub.

The nearest to the ideal method of treating large cut surfaces in pruning out branches is first to disinfect the cuts with a solution, such as mercuric cyanide or mercuric chloride, using 1 part in 1000 parts of 25 per cent alcohol. After the cut surfaces have been left to dry from a few days to a week, depending on the dryness of the atmosphere, they should then be covered with a water-tight covering, such as white lead paint, asphalt paints or some other suitable covering. Certain forms of grafting wax are also good coverings, but are usually rather expensive.

Another source of infection may be the soil, as in case of the brown rot fungus, *Pythiacystis citrophthora.* So far as known, there is no particular means of treating the soil itself, the avoidance of the disease in this case being brought about either by preventing the fungus spores from splashing up against the fruit or by protecting the fruits with some fungicidal spray.

In root rots, such as that caused by the fungus *Armillaria mellea*, the principal source of infection may be within the soil itself, *e.g.*, the infested roots of a diseased tree that has come in contact with the roots of a healthy tree, or the dead parts of an infested tree that previously grew in the same space now occupied by the Citrus tree. In the latter case sanitation may consist in removing as far as possible all dead roots and pieces of wood or bark at the time of planting the orchard, thus avoiding this source of infection in the soil.

While spraying might be considered a phase of orchard sanitation, it will be discussed under another heading. Cutting or gouging out of diseased tissues and the application of disinfectants are discussed in connection with special diseases.

Other phases of orchard sanitation are: care in the handling of trees in planting, to avoid unnecessary injuries to the bark and roots; care in budding over trees from one variety to the other; care in irrigating, to avoid too much water, or allowing the trees to dry too much between irrigations; the avoidance of sunburning, frost injury or injury from rodents. The relation of cultural practices to Citrus diseases is discussed more in detail in Chap. VII.

Spraying.—Spraying has become in some cases an important method of controlling certain Citrus diseases due to microorganisms and insects.

The principle on which spraying for infectious diseases is based consists in covering the surface with a material which will kill the germinating parts of the organisms before they have had time to penetrate the tissue and set up harmful actions. In some cases, as in mildew, spraying may also actually kill some of the superficial hyphæ that would otherwise produce an abundance of spores as sources of infection. Spraying may also cut down sources of infection from the saprophytic spore stages of certain disease-producing fungi.

The most commonly used sprays for the protection against these microorganisms are those containing copper or sulfur compounds, and, of these, Bordeaux mixture and lime-sulfur solutions are perhaps the most widely used.

In California the main Citrus disease for the prevention of which spraying is extensively used is brown rot of lemons due to *Pythiacystis citrophthora*, which fungus also causes Pythiacystis gummosis of the trunk and main roots. In recent years some spraying with Bordeaux mixture has been done on a small scale for Citrus blast in northern California, but as yet such spraying has not been used extensively for the control of this disease.

In Florida, spraying with both lime-sulfur and Bordeaux mixture has been used for the control of such diseases as verrucosis or scab, melanose and stem-end rot. In climates like Florida, where there are beneficial fungi that help to keep down the scale insects, spraying with Bordeaux mixture has been found to result in a great increase of these insects—sometimes to such an extent that the increased insect infestation is more harmful than the disease prevented. This danger has been overcome to a large extent by using Bordeaux-oil emulsion and, at times when scale insects tend to increase, by a later spraying with oil emulsion.

In the use of sprays for the prevention of any disease, it is important so to time the spraying that it will give the maximum protection. In some cases the tissue may be susceptible for only comparatively short periods while it is young and rapidly growing, and if it is protected at this stage it will later become immune to attack. This practice is especially important in the prevention of scab and melanose by spraying, the details of which will be found discussed under these diseases.

The Resistance of Species and Varieties.—One of the most effective means for the prevention of diseases when exclusion has failed is the employment of resistant varieties or species. This resistance may be partial or complete; complete resistance is spoken of as "immunity." While there may be a partial resistance due to the condition of the plant, the resistance that is thoroughly effective in the prevention of diseases is one that is an inherent property of the plant itself. The causes for this inherent resistance of a species are for the most part obscure. It may in some cases be due to differences in morphological structure; for example, McLean and Lee (1922) have found differences in the structure and appearance of the stomata that may possibly be factors in the resistance of varieties of *Citrus nobilis* to Citrus canker. In other cases the causes are probably of a physiological or chemical nature and may lie in the quality of the protoplasm itself or in chemical substances within the tissues.

The employment of resistant stocks is one of the most important methods for the prevention of some of the root and trunk diseases; for example, the sour orange is highly resistant or almost totally immune to most of the gum diseases, such as mal di gomma and Pythiacystis gummosis. The employment of this stock when budded sufficiently high above the surface of the soil is a complete preventive for these diseases.

Between 1863 and 1870 mal di gomma almost completely killed out the lemon trees in Sicily which were budded on sweet-orange stock; the orchards since then have been largely free from disease due to the use of the sour orange as a stock budded very high, sometimes 4 to 5 feet above the surface of the soil.

The sour-orange stock is also resistant to Botrytis gummosis, psorosis, shell bark and most of the other trunk diseases. The sour orange, however, is quite susceptible to scab and to Citrus blast. It is highly probable that strains of existing varieties arising from bud mutation or otherwise may be resistant to certain diseases, and that by careful bud selection resistance may be obtained. An apparent example of strains of Eureka lemon more susceptible than others is mentioned under Decorticosis, Chap X.

There does not seem to be any easily understood law governing the resistance and susceptibility of some of the common commercial species and varieties of Citrus. This is shown by the following table for four species: sweet orange (*Citrus sinensis*), grapefruit (*C. maxima*), lemon (*C. limonia*) and sour orange (*C. aurantium*).

	Susceptible	Immune or very highly resistant
Pythiacystis	Lemon Sweet orange Grapefruit	Sour orange
Psorosis	Sweet orange Grapefruit	Sour orange Lemon
Decorticosis	Lemon	Sour orange Sweet orange Grapefruit
Scab	Sour orange Lemon Grapefruit	Sweet orange
Canker	Grapefruit Sweet orange Lemon Sour orange	

It will be seen from this table that, while the lemon, orange and grapefruit are susceptible to Pythiacystis gummosis, the sour orange is resistant; when it comes to psorosis the sweet orange and the grapefruit are susceptible and the lemon stands with the sour orange in resistance. With reference to decorticosis or shell bark, we have a still different combination, in which the lemon alone is susceptible and the sweet orange, grapefruit and sour orange are resistant. In scab there is a fourth combination, in which the sour orange, the lemon and the grapefruit are susceptible and the sweet orange is resistant. A fifth combination is found in canker, when all four species are found to be susceptible. It is interesting to note that none of these combinations are the reverse of any other in susceptibility and resistance. Reverse combinations might be found, as leprosis, for example, to which sweet orange alone is susceptible, but to which the other three species are practically immune; the opposite condition to that of scab. Many other examples might be cited of resistance of species and varieties, but the above are sufficient to show the possibilities in this line in the way of prevention of diseases by selection and hybridization. Special cases are taken up under individual diseases.

In this connection there would appear to be a very important field for the economical control of diseases by the production by hybridization of new varieties of Citrus that will be more resistant to important diseases. New varieties and little-known species exist in the Old World and these may serve as resistant parent plants in hybridization or as resistant stocks. As stated in Chap. I, it is very important from the standpoint not only of selection for disease resistance, but also of breeding either stocks or new fruits adapted to special soils or climates, that a thorough taxonomic as well as pathologic study be made of the wild relatives of Citrus.

Exclusion.—In the last few years a theory has been evolved by plant pathologists which, in substance, is as follows. In countries where a crop is indigenous or has been cultivated for centuries, there will be found the greatest number of infectious diseases and parasitic insects attacking it.

Citrus fruit is a very good example in support of this theory. The sweet orange, *Citrus sinensis*, is believed to be indigenous and is known to have been grown in China for centuries. The East Indian pummelos, *C. maxima*, from which our American-grown grapefruits have presumably arisen, are believed to be indigenous to the southeastern Asiatic countries and islands. The calamondin, *C. mitis*, is a native of the Philippines, and the mandarin oranges, *C. nobilis*, are certainly of ancient cultivation in Asia. In general, then, most of the cultivated Citrus species have originated from the southeastern or southern Asiatic countries or islands.

Correlated with this evident origin of Citrus fruits of Asiatic countries is the occurrence in such countries of a large proportion of the commonly known Citrus diseases. Thus, in southeastern Asia the following diseases occur: mal di gomma, psorosis, leprosis or nailhead rust, rubellosis or pink disease, Armillaria root rot, Citrus canker, melanose, scab, anthracnose of oranges and lemons, greasy spot, exanthema, a Citrus knot, sooty mold, mildew, alga spots, blue mold, black rot of oranges, the flowering parasite Loranthus, inspissosis or dry rot of fruits, bark rot of mandarin orange trees, anthracnose of mandarin oranges, Phyllosticta leaf spot, hyaline rot of Citrus fruits of Japan and black spot caused by the fungus *Phoma citricarpa*. Of this list of twenty-four Citrus diseases, the first nineteen mentioned are common to both the western and eastern hemispheres, but the last five mentioned are found only in Asiatic countries and have not been reported as yet from occidental countries. Of the diseases common to both the eastern and western hemispheres, moreover, Citrus canker and scab are known rather definitely to be comparatively recent introductions from the eastern hemisphere, while foot rot, psorosis, leprosis, melanose and powdery mildew were probably introductions at some time in the past. The list of diseases in Asiatic countries must still be considered far from complete, since pathological studies there have been very limited. Southeastern Asia has not yet been completely explored by Citrus pathologists, and there has been no continuous study in this region.

Only a few of the commonly known diseases of the western hemisphere have not been reported from Asiatic countries and several of these undoubtedly will be found when continuous investigations become possible there. Pythiacystis gummosis and brown rot, decorticosis, Rosellinia root rot, Florida Citrus blight, Citrus blast, anthracnose of limes and cottony rot of lemons have not yet been reported from the Far East. One would expect Botrytis gummosis to be very widespread because of the probable universal occurrence of the causal fungus, *Botrytis cinerea*. The small number of true lemon trees, *Citrus limonia*, grown in oriental countries at the present time probably accounts for the absence of records of lemon diseases such as these in the western hemisphere. A fungus on Citrus trees very closely related to Rosellinia has been reported from India. Others of these diseases may be found in these far-eastern countries, when more complete studies can be undertaken in oriental countries.

With this viewpoint regarding the origin of Citrus species and Citrus diseases, it becomes immediately apparent that there are a number of serious diseases of Citrus which do not yet occur in the western hemisphere and that every means should be employed to prevent their introduction. Such diseases as bark rot might be very serious in a region such as the Gulf states where Satsumas are so generally grown. Pink disease might prove troublesome in Florida. The Phyllosticta leaf-spot disease of Japan causes a serious leaf drop which very much resembles coffee blight in its type of injury; every precaution should be taken to keep it out of California and other occidental Citrus-producing countries. Phyllosticta leaf drop occurs in the autumn months in Japan, when climatic conditions are very similar to those of California in the winter months.

In past years much benefit has been derived from the introduction of new Citrus species and varieties, the Washington Navel being an example. On the other hand, there are several instances in which the Citrus industry of a country has suffered heavily by the introductions of new Citrus plants. Citrus canker and scab in Florida are examples of the serious diseases imported with new plants.

It is possible, however, to derive the benefit of introductions of Citrus species and varieties without the losses resulting from the importation of new diseases. The measures to be undertaken consist of plant inspection and quarantine practices as follows:

1. The bud wood or seeds of the variety to be introduced should be carefully selected from disease-free plants in the country of origin. This is the most important measure and should only be undertaken by a well informed professional Citrus grower or Citrus pathologist.

2. The plant material to be imported should be carefully inspected for diseases and insects at the time of its entrance into the country where it is to be cultivated.

3. The imported plant materials should be grown in quarantine for one year, or, better, for several years, during which time observations should be made to determine the presence or absence of new Citrus diseases.

4. The introduced plants in the later stages of the quarantine period should be grown in close proximity to plants of other Citrus species and varieties. This last procedure is desirable in order to detect the presence of diseases to which the introduced plant might be resistant, although nevertheless a carrier, while related species or varieties might be susceptible.

Swingle, Robinson and May (1924) have recently outlined the efficient measures now being taken to prevent Citrus diseases from spreading on new introductions in the United States.

Citrus canker is a good example of a disease which may be introduced on a resistant host acting as a carrier. In South Africa, Satsuma orange trees were introduced from Japan. The Satsuma, being somewhat resistant to canker, did not evidence its presence. On being planted in South Africa, however, in proximity to grapefruit trees, an outbreak of canker very quickly developed on the more susceptible grapefruit trees and the disease became well established. The planting of related species and varieties of Citrus near the introduced plants, as indicated in paragraph 4 above, is, therefore, an important method of detecting possible new diseases. Under such quarantine conditions a new disease could be detected, eradicated and thus excluded before it had become established in commercial orchards.

Exclusion of new Citrus diseases by plant inspection and quarantine measures, which at the same time allows for introduction of new species and varieties, is one of the most essential and economical measures which can be undertaken to protect the Citrus industry of any country.

CHAPTER VI

FUNGICIDES, DISINFECTANTS, PAINTS AND WAXES

FUNGICIDES AND DISINFECTANTS

The term "fungicide," broadly considered, is any substance used to kill or to prevent the growth of fungi, including bacteria. The term "disinfectant" is broader in its meaning and may be applied, not only to fungicides, but also to substances that either kill or prevent infection from any organism either vegetable or animal in nature. Those employed to kill insects are usually known as insecticides. Most of the so-called disinfectants employed on Citrus trees or fruit are fungicides; some disinfectants are both fungicides and insecticides as well.

Fungicides and disinfectants are used on Citrus trees (1) as sprays, to prevent infection by parasitic fungi; (2) as washes or paints, to prevent infection from bark diseases or to disinfect wounds made in treatment of the same, and to disinfect wounds made in severe pruning or grafting; and (3) as a dip, for the prevention of infection in washing of fruit at the packing house or as a disinfectant for parts of the packing house itself. Disinfectants may also be employed as dips for seeds or parts of trees to be sent from one section or country to another to prevent the introduction of new diseases.

Copper Compounds

Bordeaux Mixture.—Bordeaux mixture either alone or with oil emulsion is one of the most commonly used spray mixtures for Citrus diseases. It is especially valuable for prevention of fungus diseases, such as scab, melanose, brown rot and other fruit and leaf diseases. It is usually considered one of the most effective and persistent fungicides for most kinds of fungus diseases. Experience in recent years in Florida and California has indicated that the strength of mixtures formerly employed, such as 5-5-50, may be reduced to 3-3-50 and good results still be obtained. The mixture now regarded as sufficient for most Citrus spraying consists of:

Copper sulfate (blue stone)	3 pounds (1.5 kilos)[1]
Stone lime	3 pounds (1.5 kilos)
Water	50 gallons (200 liters)

---

[1] Throughout the discussion of fungicides and disinfectants, a quart is translated as a liter, a gallon 4 liters, a pound 0.5 kilo and an ounce 30 grams. Although this is only approximately correct, it makes the relative proportions sufficiently correct for the purpose.

This is a 3-3-50 formula. To make convenient stock solutions, proceed as follows:

1. Dissolve copper sulfate at the rate of 1 pound in each gallon (0.5 kilo in 4 liters) of water in wooden, earthenware or glass vessel (never in metal containers). Solution may be facilitated by suspending the copper sulfate in a sack in the top part of the water.

2. Slake the stone lime in water at the rate of 1 pound to each gallon of water. These two stock solutions may be kept indefinitely if prevented from drying out.

For a 3-3-50 mixture, 3 gallons (12 liters) of (1) and (2) are sufficient for 50 gallons (200 liters) of spray solution. For a spray tank of 200-gallon capacity, 12 gallons of the stock copper sulfate are added, the tank filled one-half full or more and then 12 gallons of the stock lime solution added while the agitator is running. The tank is then filled to make the total of 200 gallons.

Bordeaux-oil Emulsion.—Where beneficial fungi are important in keeping down the increase of scale insects, as in Florida, an oil emulsion added to the Bordeaux mixture is desirable. Bordeaux also aids in the better mixture of oil emulsions in extremely "hard" waters.

For a 200-gallon spray tank, make the stock solutions as described under Bordeaux Mixture. Fill the tank three-fourths full of water and pour into it, through a strainer, 12 gallons of the stock lime solution. While this is being agitated, pour in 12 gallons of the stock solution of copper sulfate, add enough oil emulsion to make 1 per cent of actual oil while the Bordeaux mixture is being agitated. Then fill up the tank with water to make 200 gallons. Hydrated lime has been tested by Winston and Bowman (1923*b*) in making some Bordeaux-oil emulsions which proved as good for controlling melanose and scab as that made with stone lime. Four pounds of hydrated lime must be used for each 3 pounds of stone lime.

Oil Emulsions for Bordeaux Mixture.—In making the Bordeaux-oil emulsion, commercial oil emulsions may be used, or they may be prepared by the grower. The following method of preparing a satisfactory emulsion is given by Yothers (1918*a*):

Paraffin oil	2 gallons (8 liters)
Water	1 gallon (4 liters)
Caustic potash—fish-oil soap	2 pounds (1 kilo)

Place the oil, water and soap together in a kettle or other vessel and heat to the boiling point. Remove from the fire and, while the material is still hot, pump it into another vessel and then back again with a bucket pump.

Bordeaux Paste or Wash.—For prevention of Pythiacystis gummosis, mal di gomma or other trunk and bark diseases, as well as for treatment after the diseased tissues have been cut away, a Bordeaux paste or wash has been commonly employed with good results. This is especially useful also on susceptible tree trunks, bases of large roots in very heavy soils after pulling the earth away from the crown. The strength originally used by Fawcett consisted of:

Copper sulfate	4 pounds (2 kilos)
Stone lime	8 pounds (4 kilos)
Water	6 gallons (24 liters)

For stock solutions: (1) Dissolve 4 pounds of copper sulfate (blue stone) in 3 gallons of water in a wooden, earthen or glass vessel. This is easiest dissolved by suspending it in a sack in the top of the water overnight. If pulverized and suspended in warm water it dissolves rapidly. (2) Slake 8 pounds of stone lime in 3 gallons of water (if stone or unslaked lime cannot be obtained, use hydrated lime increased by one-third). If covered to avoid evaporation each ingredient will keep indefinitely, but, after mixing, the paste or wash slowly deteriorates. Where it is being used over a number of days or weeks, enough of the wet slaked lime and the blue-stone solution may be mixed to make enough paste to last for one day, leaving the remainder unmixed in separate vessels. About equal parts of volume of the two stock ingredients may be used. When made with good lime it is about the consistency of a thin paste or a thick whitewash, and may be applied with large brushes, like whitewash. Experience has indicated that thinner preparations, using up to twice as much water or making a 10-10-50 Bordeaux mixture, are also effective for the prevention and treatment of bark diseases.

Copper Sulfate Solutions.—A solution of copper sulfate (blue stone) alone is also in use for the prevention of brown rot in the washing of Citrus fruits, especially lemons, in California. The copper sulfate is used at the rate of one to 1½ pounds to 1000 gallons of water in the washing tanks or in separate tanks through which the fruits pass after they have gone through the washing machine. The stock solution of 1 pound to 1 gallon (0.5 kilo to 4 liters) of water is kept at hand and this is used for obtaining the proper strength. In recent years hot water in the washing tank is frequently substituted for this copper sulfate solution of former years. Some packing houses use both the hot water and copper sulfate. Copper sulfate is also used with or without lime to disinfect the walls and floors of Citrus packing houses. It also has a use in keeping down algæ in irrigation reservoirs. Copper sulfate in the crystalline form is spread on the ground by some growers in Florida as one of the palliatives for exanthema.

Burgundy Mixture.—This mixture may be substituted for Bordeaux mixtures in localities or situations where it is impossible to obtain good lime. Its fungicidal value is considered about equal to that of Bordeaux mixture and it does not leave so much color on the foliage or fruit as does the latter. It probably does not adhere so well through rains as Bordeaux, and is usually more expensive. For a 4-5-50 formula use:

Copper sulfate	4 pounds (2 kilos)
Washing soda (sodium carbonate)	5 pounds (2.5 kilos)
Water	50 gallons (200 liters)

The copper sulfate is dissolved as for regular Bordeaux mixture, 1 pound to a gallon. The sodium carbonate may be readily dissolved just before using. For 200 gallons fill the spray tank two-thirds full of water. Then pour in 16 gallons of the stock copper sulfate, and, while agitating, pour in water in which 20 pounds of sodium carbonate has been dissolved; then fill the tank with water. A Burgundy paste may also be made (Nowell 1923) with

Copper sulfate	4 pounds (2 kilos)
Sodium carbonate	5 pounds (2.5 kilos)
Water	4 gallons (16 liters)

(1) Dissolve 4 pounds of copper sulfate in 3 gallons of water as for Bordeaux paste. (2) Dissolve 5 pounds of sodium carbonate in 1 gallon of water. Use 3 parts of (1) to 1 part of (2) to make the paste. The addition of milk, $\frac{1}{4}$ pint to a gallon of mixture or resin soap, will increase adhesion.

Ammoniacal Copper Carbonate.—This mixture is sometimes used as a substitute for Bordeaux mixture. It has the advantage of not leaving any visible residue on the leaves or fruit on drying. It appears, however, to be more readily washed off by rains and is not so permanent as Bordeaux mixture. The usual formula is:

Copper carbonate	5 ounces (150 grams)
Ammonia (26°Bé.)	3 pints (1.5 liters)
Water	50 gallons (200 liters)

The ammonia is first diluted with 1 gallon of water. The copper carbonate is made into a paste with water and slowly added to the dilute ammonia. Water is then added to make 50 gallons. For a 200-gallon tank the formula is, of course, multiplied by 4. (A mixture of the same character may be made by adding ammonia to Burgundy mixture until the precipitate is dissolved.)

Colloidal Copper.—Colloidal copper is being experimented with in connection with certain plant diseases, and will probably come into prominence as a fungicide in the near future. No extensive tests have yet been made with this product in connection with Citrus diseases, so that definite formulæ cannot be given here.

SULFUR COMPOUNDS

Probably the most common spray materials, besides forms of copper sprays, such as Bordeaux mixture used on Citrus trees as fungicides, are various forms of sulfur compounds. These have the advantage of serving also as insecticides. Unfortunately, they are not so efficient against many of the fungus diseases, except in very high concentrations, as are the copper sprays. In Florida they have come into use as a fungicides for part of the spray schedule for melanose and scab (Winston 1923), as a partial substitute or supplement to Bordeaux-oil emulsion. Colloidal sulfur has recently come into use as an insecticide and will probably be very useful as a fungicide as well.

Commercial Lime Sulfur.—Concentrated lime-sulfur solutions made by commercial firms are sold in barrel lots or smaller amounts, such as 5- or 1-gallon cans. These solutions are diluted on a basis of a test of 32°Bé., which is the usual standard for concentration (see dilution table under next heading). For fungicidal purposes on Citrus, as for scab and melanose in Florida, these are used at a strength of 1 to 25 or 1 to 30. For use in keeping the bark of trunk and large limbs free from moss, lichens, etc., they may be used 1 to 7 to 10 gallons. For insecticidal purposes alone, as for red spider, rust mite, etc., they may be used at greater dilutions.

Home-made Concentrated Lime-sulfur Solution.—With the necessary equipment, lime-sulfur solutions may be prepared by the Citrus orchardist, usually at less cost than the commercial product. The following method for preparing a stock solution is described by Stevens (1918):

Stone lime (95 per cent CaO)	50 pounds (25 kilos)
Flower of sulfur	100 pounds (50 kilos)
Water	50 gallons (200 liters)

An iron kettle or feed cooker of 60- or 75-gallon capacity and a sufficient number of barrels to store the finished product should first be provided.

Weigh out the required amounts of lime and sulfur and sift the latter to remove any lumps. Place 10 gallons of water in the cooker and start the fire. Add the lime and when slaking has well started add the sifted sulfur. Add sufficient water to make a thin paste and mix thoroughly. When the slaking has finished, enough water should be added to bring the total up to 55 or 60 gallons. The solution should boil vigorously for fifty to sixty minutes and will require constant stirring during this period. Do not let the total volume of the solution fall below 50 gallons and avoid either over or undercooking. It is important that the solution boil vigorously and constantly for at least forty-five minutes. After the boiling has finished, allow the solution to cool and settle. It may be necessary to draw the fire to prevent further boiling. When sufficiently cool, the solution should be strained to remove any coarse sediment. It can then be diluted for use or stored in the concentrated form.

The finished product should be an amber-colored liquid with little or no sediment. It will keep fairly well if properly stored to exclude the air, but no more than can be used during the season should be made at one time. If closed barrels are used, they should be completely filled and the holes tightly closed. When any of the solution is drawn from the barrel, or when the solution is stored temporarily in open barrels, a covering of oil may be poured on the surface to exclude the air. Paraffin or engine oil may be used for this purpose.

Since dilutions are usually made on the basis of a concentration of 32° Bé. as shown by the hydrometer scale, the finished product may be tested and the desired dilution with water be obtained by the use of the following table.

DILUTIONS FOR LIME SULFUR

Stock solution, degrees Baumé	Standard dilutions for 32°Bé., in gallons			
	1 to 25	1 to 30	1 to 35	1 to 40
25	18	22	25	29
26	19	23	26	30
27	20	24	28	32
28	21	25	29	34
29	22	26	30	35
30	23	27	32	36
31	24	28	33	38
32	25	30	35	40
33	26	31	36	41

Lime-sulfur-oil Emulsions.—A combination spray which has been found by Yothers (1924) to be highly effective when used against scale insects, white flies and rust mites in Florida consists of the following:

(*a*)	Paraffin oil or lubricating oil	2 gallons (8 liters)
	Water	1 gallon (4 liters)
	Caustic potash, fish-oil soap	2 pounds (1 kilo)
	Glue or other stabilizer	1 pound (0.5 kilo)

(*b*) The above with 4 to 6 gallons of lime sulfur (32°Bé.) is put into a 200-gallon tank of spray material.

Put the oil, water, soap and stabilizer of (a) into a kettle or other vessel that will stand fire and heat to the boiling point. While the liquid is still very hot, but after it has been removed from the fire, pump it into another vessel with a bucket pump and then pump back again. The quantities stated in the foregoing formula are for use with about 200 gallons of water or with the same volume of diluted lime-sulfur solution.

If an emulsion thus made is used in a few days, no preservative is needed; otherwise a preservative will be necessary to prevent fermentation.

In order to render oil emulsions miscible, so that they will mix with either deep-well waters or diluted lime-sulfur solutions, the following quantities of the various stabilizers are required for each 3 gallons of emulsion:

PROPORTIONS OF STABILIZING SUBSTANCES

Glue	1 pound	Wheat flour	1 pound
Skimmed-milk powder	1 pound	Cornstarch	1 pound
Casein	8 ounces	Laundry starch	1 pound

Lime-sulfur Washes and Paste.—Lime-sulfur washes or pastes are useful for application to the trunks or roots as a substitute for Bordeaux paste. These may be made in several ways. Two methods are suggested as follows:

1. Take 1 gallon of concentrated lime-sulfur solution and mix with 2 gallons of lime paste made by slaking 3 pounds of stone lime to each gallon of water.

2. Take 8 pounds of stone lime and place in a barrel. Add water, and while the lime is slaking sift slowly into it 8 pounds of flowers of sulfur, constantly stirring. Add only enough water to make a smooth, thin paste.

Colloidal Sulfur.—Colloidal sulfur is now coming into use as an insecticide on Citrus. It has the advantage of being in a very finely divided form and will probably be much superior to ordinary sulfur as a fungicide as well as an insecticide. Colloidal sulfur may be made from lime sulfur by precipitation with sulfuric acid. It is being manufactured by commercial firms and may be bought already prepared.

MISCELLANEOUS DISINFECTANTS AND FUNGICIDES

Mercuric Chloride (Corrosive Sublimate).—Mercuric chloride, also known as bichloride of mercury and corrosive sublimate, is a white crystalline powder which is a very efficient disinfectant for many purposes. It has been used with safety for the disinfecting of Citrus seeds at a strength of 1 part of mercuric chloride to 1000 parts of water. It may be bought in the form of tablets; if the crystalline powder is used, the formula will consist of:

Mercuric chloride	⅛ ounce (4 grams)
Water	1 gallon (4 liters)

The solution should not be placed in metal containers. For the disinfecting of wounds on the bark it is advantageous to have at least 25 per cent of the liquid consisting of denatured alcohol and the remainder of water. This causes the substance to penetrate and wet the entire surface more readily. This material has been used safely on the mature bark at a strength of 1 part mercuric chloride to 500 parts of a watery solution containing denatured alcohol as one-fourth of its volume. The formula would then be:

Mercuric chloride	¼ ounce (8 grams)
Denatured alcohol	1 quart (1 liter)
Water	3 quarts (3 liters)

Mercuric Cyanide.—Mercuric cyanide is also a white cystalline substance of the same appearance as mercuric chloride. In experiments in the treatment of pear blight it has been found by Reimer superior to the mercuric chloride for treating the wound made in pruning. It has recently been used as an application in the treatment of psorosis and shell bark with apparently good results. Like mercuric chloride, it may also be used on cuts made in pruning out large limbs and for disinfecting wounds in tree surgery work. For use on tender tissues it may be made up in a preparation of 1 part to 1000 parts of water. For use in connection with psorosis, gummosis and shell bark it may be used as strong as 1 part to 500 parts of a watery solution containing denatured alcohol as one-fourth of its volume. The alcohol is added for the purpose of causing it to penetrate and wet the surface more readily.

As with mercuric chloride, this substance may also be obtained either as tablets or in the crystalline form. For use on bark, the formula would consist of:

Denatured alcohol	1 quart (1 liter)
Mercuric cyanide	¼ ounce (8 grams)
Water	3 quarts (3 liters)

First dissolve the mercuric cyanide in the water and then pour in the alcohol. For tender tissue use one-half as much mercuric cyanide.

The mercuric chloride and mercuric cyanide may be mixed in equal quantities for disinfecting both wounds and tools.

Potassium Permanganate.—Potassium permanganate has been used recently as a disinfectant in connection with the treatment of psorosis on orange trees. It has been used safely on bark at a strength of 1 per cent or higher. This would be about an ounce of potassium permanganate dissolved in 3 quarts of water, or about 30 grams to 3 liters. This strength may be approximated by using 1 teaspoonful to a pint of water. It forms a reddish solution which may be applied with a brush. It is an active oxidizing agent.

Borax.—Borax has recently come into use in connection with the prevention of decay, especially the green-mold decay due to *Penicillium digitatum* on Citrus fruits. It is used in a separate tank through which the fruits pass after they have gone through the washing machine. Borax is not a strong disinfectant in itself as compared with many other substances, but it seems to have some influence, not entirely understood, on the rind of the fruit, which enables the solution to prevent the development of some of the decay brought about by the blue and green molds, especially the latter.

Chloride of Lime or Bleaching Powder.—A substance that is very commonly used for disinfecting purposes and also for deodorizing is chloride of lime, perhaps more commonly called chlorinated lime. This is useful in packing house storage rooms where a great deal of decay has taken place and the disintegrated fruits have run out upon the floor. It may be used in scrubbing the floors and deodorizing these basement rooms. It is less expensive than some other disinfectants when used in large quantities.

Whitewash.—Whitewash is useful for a variety of purposes in connection with Citrus. Its most common use is for the covering of the trunk and large limbs to prevent sunburning, especially when trees are severely pruned or when they may be considerably opened up for the treatment of bad cases of psorosis or other diseases on branches.

Whitewash is also useful for application to the walls and ceiling of packing houses.

A formula to prevent sunburning of trees is:

Stone lime	50 pounds (25 kilos)
Water	10 gallons (40 liters)
Salt	4.5 pounds (2.25 kilos)

or

Hydrated lime	50 pounds (25 kilos)
Water	8 gallons (32 liters)
Salt	4 pounds (2 kilos)

In making good whitewash from stone lime the water should be poured on in such a way in slaking that the lime is not burned by becoming too hot. Slaking may be hastened, especially in cold weather, by placing a burlap sack over the container to conserve the heat. The amount of water added may vary, depending on whether the whitewash is to be put on with a brush or with a spray outfit. It may be used somewhat thicker and without straining if it is to be put on with a brush. If a spray outfit is used, it will be necessary to strain out the lumps. The addition of the salt makes the whitewash much more enduring and perhaps causes it to penetrate all irregularities of the bark more readily. The hydrated lime may be used in case stone lime cannot be obtained, but it is usually considered less adhesive and possibly less durable than whitewash made with the stone lime.

When cactus juice is available this may be used to increase the adhesiveness of ordinary whitewash. The cactus stems may be chopped up and soaked overnight in water and this used as part of the liquid for the whitewash.

In case whitewash is used for application to the interior of packing houses and in large quantities, a slightly different formula has been found satisfactory, namely:

Stone lime	About 60 pounds (30 kilos)
Rye flour	2.5 pounds (1.25 kilos)
Salt	1.5 pounds (0.75 kilo)
Water	About 20 gallons (80 liters)

This is best made by slaking the lime in a barrel in about three-fourths of the water necessary to make the completed product. The rye flour may be beaten up in ½ gallon of cold water and then 2 gallons of boiling water added. The salt may be dissolved in about 3 gallons of hot water and mixed with the flour paste; then the mixed flour and salt may be poured into the lime, while it is being stirred. The purpose of the flour is to make the whitewash more adhesive. If the spray outfit is to be used, it will be necessary to strain out the coarse particles. Rock salt may be used instead of common salt because of its cheapness.

Some recent tests with various formulas for whitewash have apparently shown (Fink 1922) that the so-called government formula, so widely used, is no better in durability and is perhaps less adhesive than the simpler formula given above.

Formalin (40 Per Cent Formaldehyde).—Formalin is a common disinfectant which may be used as a substitute for some of the others previously mentioned, in case they are not at hand. Since the formaldehyde is a gas, this disinfectant is more volatile and does not have the lasting effects of some of the others. It has its advantages where one wishes to disinfect surfaces temporarily, and to have all the products of the disinfectant disappear. A solution 2 to 4 per cent of formalin may be used to disinfect field boxes in the packing house. In case a greater penetration is desired, denatured alcohol may be used as part of the solution. This disinfectant is more expensive to use on a large scale than some of the others.

Crude Carbolic Acid (Coal-tar Creosote or Creosote Oil).—A substance known as crude carbolic acid was at one time used to a considerable extent in the treatment of brown rot gummosis, mal di gomma and psorosis. Although it is not being used so commonly as before, it should be mentioned here because of the great variation in the product sold under this name.

As pointed out by Gray (1916), a large quantity of mixed residues from all sorts of tars are sold under the name of crude carbolic acid. When one buys what is said to be crude carbolic acid therefore, it is very uncertain what one may be getting. Some lots may be very injurious when applied to the bark, while others may be quite safe. Gray, says:

It is perfectly evident that in many cases the temptation to sell under one name or another, as crude phenols, every residue that cannot be sold for any other purpose is too great to be overcome, and this uncertain and variable mixture, whether good or bad in its original form or after doctoring, masquerades under hundreds of fanciful names and finally falls into the hands of the unsuspecting consumer.

In a series of analyses of substances going under the name of crude carbolic acid in California, Gray found that they varied in the percentage of phenols all the way from 5 to 28 per cent. The use of crude carbolic acid should, therefore, be discontinued when possible in favor of more certain and reliable materials. If pure carbolic acid is used on bark of Citrus, for safety it should not be stronger than 5 per cent in water.

Carbon Bisulfid.—Carbon bisulfid is a clear liquid that volatilizes quickly, forming a gas. It is used as an insecticide, also in the killing of squirrels and gophers. It has been used to a considerable extent also for killing the oak root fungus, *Armillaria mellea*, in the soil. It is poured into holes made in the soil and the gas penetrates through the soil spaces into the roots, killing the fungus (see Armillaria Root Rot, p. 95).

Carbolineums.—Certain kinds of high-boiling, coal-tar products known as carbolineum are used on the bark of Citrus trees for the prevention and treatment of certain diseases, such as mal di gomma, Pythia-

EFFECT OF VARIOUS "CARBOLINEUMS" ON CITRUS TREES
(Experiment Aug. 11, 1923; Results about Aug. 16, 1923)[1]

No.	Name	Leaves on tree	Fruit on tree	Twigs	Remarks	Examined Nov. 23, 1923. Trees 15 years; bark thick; scraped bark on trunk
1	P. S. No. 327,[2] Arrow carbolineum. Phenols 0.7 per cent.	− to 0	0	0	No injury to older leaves on tree	No killing of bark tissue
2	P. S. No. 326, Avenarius carbolineum. Phenols 0.3 per cent.	− to 0	0	0	No injury to older leaves on tree	No killing of bark tissue
3	App. No. 408, carbolineum. Phenols 2.6 per cent.	− to 0	+	0	Injury to leaves and fruit, slight in most cases	No killing of bark tissue
4	Lab. No. 2363, "carbolineum." Phenols 10.8 per cent.	++	−	+	Severe burning	Thick outer layer of bark peeling; not killed through
5	Lab. No. 2369 "carbolineum." Phenols 10.8 per cent.	+	+	−	Severe burning on leaves and fruit	Small place in center where scraped deeper is killed; thick outer layer peeling
6	Lab. No. 2362 "carbolineum." Phenols 21 per cent.	++	++	+	Very severe injury to leaves and fruit	Same as No. 5

---

[1] General results: 0, no injurious effect; −, slight injury; +, considerable injury; ++, severe injury.

[2] See analyses corresponding to these numbers in the next table.

CARBOLINEUMS[1]

Results of examination	Causing no injury[2]		Causing slight injury	Causing severe injury		
	"Avenarius" P. S. 326	"Arrow" P. S. 327	App. No. 408	Lab. 2363	Lab. 2369	Lab. 2362
Specific gravity at 38°C.	1.1196	1.1299	1.0660	0.8670	0.9620	0.9100
Flash point, degrees Centigrade	156	142	103	79	84	88
Burning point, degrees Centigrade	199	211	107	85	97	92
Distillation below 250°C., per cent	0.0	1.32	18.68	52.09	46.72	36.09
Distillation between 250 and 300°C., per cent	11.56	7.74	32.53	38.38	14.15	16.14
Total distillation below 300°C., per cent	11.56	9.06	51.21	90.47	60.87	52.23
Distillation between 300 and 360°C., per cent	57.14	43.92	33.95	7.22	29.90	27.29
Residue above 360°C., per cent	31.30	47.02	14.84	2.31	9.23	20.48
Total distillation above 300°C., per cent	88.44	90.94	48.79	9.53	39.13	47.77
Ash, per cent	0.19	0.08	0.004	0.001	0.02	0.08
Water, per cent	Trace	Trace	Trace	Trace	0.20	0.30
Naphthalene	Very small	Small	Small	Nil	Nil	Nil
Anthracene	Test positive	Test positive	Test positive	Trace	Trace	Test negative
Total tar acids, per cent	Small	Small	5.10	12.00	17.92	21.62
Phenols (Chapin method), per cent	0.31	0.73	2.60	10.80	14.50	21.00
Benzol insoluble, per cent	....	....	0.02	0.007	0.02	0.002
Chlorin, per cent	0.48	0.39	0.03	0.06	0.08	0.40
Unsulfonated residue of distillation above 300°C., per cent	Nil	Nil	Nil	77.20	38.40	66.00

---

[1] Analyses from Gray and Colby (1924).

[2] See preceding table.

cystis gummosis and psorosis. They are also used in painting cuts resulting from pruning out large limbs and in disinfecting wounds made in the removal of decayed cavities. They are also useful as a repellant for ants, termites and other insects.

There are many kinds of substances at the present time sold under the name of carbolineum which vary greatly in composition and some of which are very injurious to Citrus bark, while others are entirely safe. The degree of injury probably depends to a great extent on the percentage of phenols (tar acids) which they contain. The injury will also probably depend on whether they are low-boiling compounds as compared with the high-boiling, non-injurious types. A carbolineum, in order to be safe to use on the bark, should be a high-boiling compound containing low amounts of phenols or tar acids. Avenarius and Arrow carbolineums of the analyses shown in the following table have been tested out and shown to be safe. These have phenols as low as 0.3 to 0.7 per cent. Other types which have been sold under the name of carbolineum have shown analyses (Gray 1924) with phenols as high as 10.8 to 21 per cent, and these, when tested out alongside of the others, showed very severe injury. As will be seen in the table the percentage of the products distilling below a temperature of 250°F. was from 0 to only 1.32 in the non-injurious carbolineums, but was as high as 36 to 52 per cent in the injurious substances. Below a temperature of 300°C. the non-injurious showed only 7.7 to 11.5 per cent distilling over as compared to 52.2 to 90.4 per cent in the injurious ones. The non-injurious products showed no unsulfonated residue of the distillation above 300°C., while the injurious products showed from 38.4 to 77.2 per cent. The apparent relation of the percentage of phenols and light oils to injury is shown on page 58.

Caution in Use of Carbolineums.—Because of this great variation in the products sold as carbolineum, great care should be taken not to use one that has a high percentage of phenols or that has in it a large percentage of the light penetrating oils, such as the last three samples listed in the table on page 59. As pointed out by Gray (1924):

> The unsulfonated residue is of special significance and strongly indicates, but does not absolutely prove, the addition of oils derived from petroleum. In common language, we would say that they have been mixed with distillate.

Before using any particular lot of carbolineum or other similar products on the bark in the treatment for gummosis, psorosis or shell bark, the product, should be tested out on the foliage and twigs several days before it is to be applied. If in two or three days it does not injure the mature leaves or twigs, it will then probably be safe to apply to the bark. If however, the leaves are severely burned, it should not be used. If the leaves are very slightly injured, it may still be safe on mature bark.

It should be pointed out that any material of this kind, is much more likely to cause injury to the bark in the late fall and winter than at other seasons, especially under California conditions when drying winds or frost follow the scraping of bark for diseases such as psorosis and shell bark. One of the factors at this period is probably dormancy or inactivity of the bark, which does not build up as rapidly as it does in the spring and summer. When used at any time on the bark carbolineum should be rubbed out very thin. These carbolineums usually cover a great deal more surface than most of the watery disinfectants.

Liquor Cresolis Compositus, U. S. P.—This compound or similar mixtures is also known under various names, such as Lysol, emulsified cresol and Licresol. It has both fungicidal and insecticidal properties. Liquor cresolis compositus is an emulsion containing 50 per cent cresol with 50 per cent of soap and oil. It may be obtained from drug companies and drug stores. It is very penetrating and injurious to the bark if used full strength, but may be used with safety on bark in a strength of 10 per cent in water, with which it mixes in nearly all proportions. It has been used by a number of Citrus growers recently, with apparently good results, as a disinfectant in connection with psorosis. It may be put on either with a brush or with a spraying outfit. It has the advantage of being both a fungicide and an insecticide.

Proprietary Remedies.—Many proprietary remedies are being sold or used by persons treating trees, some of which are purported to be mysterious or secret remedies of special effectiveness. As pointed out by Gray (1915), the fact that the fungicides or insecticides are of secret composition does not necessarily condemn them, but it may in many cases put them under suspicion. It is usually a good plan to discount greatly the marvelous claims regarding the properties and virtues ascribed to these secret remedies and, if possible, to make use of standard materials of known composition, or of more modest, but usually more truthful, claims. It is safer to consult some experiment station or other institution whose business it is to investigate these matters before using remedies of this type.

PAINTS, WAXES OR OTHER COVERINGS

Paints or waterproof coverings are usually applied to cuts or wounds for three supposed beneficial purposes: (1) to prevent drying out of the exposed tissues; (2) to facilitate the formation of callus and healing of the wound; and (3) to prevent wood decay.

It should be pointed out in connection with the painting of wounds that experience in recent years has shown that, under some conditions, wood decay in Citrus as well as other fruit trees is apparently favored rather than prevented by the immediate application of certain waterproof coverings to large wounds in pruning or other operations. In the warm, dry seasons during periods of active growth it may be safe to apply such coverings at the time the cuts are made, but in cooler, moist seasons when the growth is not active, or in localities especially subject to wood rots, the wounds should first be carefully disinfected, and then allowed to dry for one to three days or more before they are sealed. A large number of preparations have been used for this purpose.

Grafting Wax.—A very useful material, not only for grafting and budding but also for the painting of wounds, is a preparation of grafting wax. This may vary considerably in composition according to the season and conditions for which it is to be used.

One of the standard formulæ for grafting wax is: 1 part tallow, 1 part beeswax, and 1 part resin. The wax is stirred or pulled until it develops a yellow grain.

A useful grafting wax for covering tree wounds and top working under California conditions is made either by melting equal parts of beeswax and resin or by using 4 parts resin, 2 parts of beeswax and 1/2 part tallow.

When an especially good wax is needed for inarching, one may use 2 parts of beeswax to 1 of resin. If used under ground, more resin may be used, as 4 pounds resin, 2 pounds beeswax and 1 pound tallow.

A useful method of keeping the wax in proper condition for application is to cut out part of the side of a square oil can near the bottom and suspend another vessel in the top so that a little heat can be introduced under the wax while it is being carried from place to place.

A liquid tree wax which may be put on cold with a paint brush is made from the following ingredients:

1 pound resin (0.5 kilo).
2 ounces tallow (60 grams).
6 ounces alcohol (180 cubic centimeters).
1 ounce spirits of turpentine (30 cubic centimeters).

When preparing, the resin and the tallow are first heated together, cooled down somewhat and then the alcohol is slowly poured in while stirring; finally the turpentine is stirred into the mixture. Care should be taken not to use too much turpentine, which may cause the wax to irritate the new tissue and sometimes stimulate gum formation.

White Lead Paints.—A good grade of white lead paint is a useful covering for wounds made in pruning or grafting, to be used with the precautions indicated in the general statements (p. 79). In positions exposed to the sun it has the advantage over dark or black coverings of being less likely to result in sunburning of the parts covered. It should be renewed from time to time until the wound has healed over.

Asphalt Paints.—Paints with an asphaltum base have been used to a considerable extent on wounds made in pruning and on exposed areas of wood where bark or wood has been removed in treatment of certain diseases. The hard asphalt is sometimes heated and applied as a hot liquid. It is usually more convenient, however, in the form of a thick paint when cold.

Good asphalt paint free from impurities may be made by dissolving hard asphalt in benzine or gasoline until it has body enough to form a good covering when applied with the brush. The hard asphalt may either be broken into small pieces and dissolved in the benzine, or the asphalt may first be melted by heating, and after it has been taken from the fire and cooled down somewhat, but not enough to harden again, the benzine poured in and stirred.

Asphalt paint dissolved in benzine and put up in cans ready for use can usually be purchased at paint shops or hardware stores. A similar article dissolved in turpentine is also on the market, but is not so suitable for use on tree wounds.

A number of good proprietary products of an asphalt base nature, sold under various trade names, are also on the market.

CHAPTER VII

CULTURAL OPERATIONS IN RELATION TO CITRUS DISEASES

The Citrus Seedbed and Diseases.—Much loss from diseases is frequently experienced in the germination of Citrus seeds and the growing of young Citrus plants in the seedbeds. A considerable part of this may be avoided by careful management.

Damping-off.—This general term is applied to the effects of several different fungi. Water-soaked spots appear on the stem near the ground level. These spots become brown and sunken. The top of the plant, if quite young bends over, withers and dies. If the plant is older and has a more woody stem, it may wither and die without bending over. The diseased plants often occur in small patches, which enlarge rapidly if the soil conditions are suitable for the spread and infection of the organism. Some of the fungi which have been found in connection with the damping-off and death of young Citrus plants are species of Rhizoctonia, Fusarium, Pythium, Phytophthora, Pythiacystis, Sclerotium, Sclerotinia and Botrytis. As far as known, no careful investigations have ever been made of the exact relation of these fungi to the damping-off and death of young Citrus seedlings.

Some of the conditions which are thought to be favorable to damping-off are poor drainage, improper application of water, excessive shading, excessive air humidity, overcrowding, temperatures favorable to the growth of the fungi and unfavorable to the growth of the plants and badly contaminated soils.

Control lies largely in the careful management of the seedbed to avoid the above conditions. Good drainage should first be provided. While some shading is advisable in dry, arid climates having bright sunshine, an excess of shade should be avoided. Thorough application of water at longer intervals rather than too frequent sprinkling is desirable. Irrigation should be in small furrows, with the plants on raised ridges when possible. Since infection appears to be most common at the soil level, this part should be kept as dry as feasible. Loose sand over the top of the soil, ½ to 1 inch deep, appears to be advantageous in preventing damping-off.

In selecting a site for a seedbed, soil should be chosen that has not previously been used for that purpose. If soil previously planted or known to be infected must be chosen, it should be disinfected previous to planting. It may be treated by steam under pressure, as is done for soil sterilization in greenhouses, or by the use of 1 per cent formalin solution, 1 gallon to each square foot of soil surface. The latter is sprinkled over the surface, which is then covered for a few days with sacking or fumigation tent cloth to permit the fumes to kill the injurious soil organisms.

Rolf's Sclerotium Blight.—The fungus *Sclerotium rolfsii* not only causes a damping-off of tender seedbed plants, but also attacks older plants after they have attained a considerable growth in the seedbed. The bark at the surface of the soil and for several inches upward softens and rots, the stems are girdled and the plants killed. The fungus forms a dense, white growth in moist weather, with the formation of small brown spherical bodies (Fig. 119). The characteristic of the fungus has been described on page 367. Good drainage and the avoidance of overcrowding will help to prevent this disease.

Albino.—In the germination of nearly every lot of Citrus seeds, a certain percentage of the plants will be lacking in chlorophyll and will remain white and fail to develop into normal plants. These are worthless and might just as well be pulled out. The cause for the appearance of these albino plants is not definitely known. These albino plants are usually considered to be mutations, although this point is not definitely established. This occurrence is also frequent in the seedlings of other plants.

Bench Rooting.—A twisted or coiled condition of the root or of the lower part of the stem below the soil frequently occurs in the seedbed. This twisting appears to be due to an inability of the growing plant to break through the tough seed coat at once, and consequently the root or stem is bent or coiled before it emerges. This condition may be largely prevented by planting fresh seeds before they have dried or by soaking dried seeds from one to two days in water before planting.

Dodder.—Certain species of Cuscuta or dodder frequently give trouble in seedbeds. These are parasitic flowering plants with small, vine-like yellow stems which twine about the stems of the host. The stems of the dodder have root-like processes which penetrate the bark and take nourishment from the seedling. In rapidly growing seedlings, gall-like outgrowths have been noted where the dodder had tightly encircled the Citrus stems (Fig. 2). The vine-like parts should be carefully removed as soon as they appear in the seedbed and watch kept for further appearance of the parasite.

The Citrus Nursery and Diseases.—A number of the same diseases that occur on the root, trunk, twigs and leaves of trees in the orchard also affect trees in the nursery. Some of the problems connected with them, however, are different.

The diseases that affect the root and stem of young trees, such as Armillaria root rot, due to *Armillaria mellea*, forms of gummosis, due to

Phytophthora parasitica, *Pythiacystis citrophthora*, *Sclerotinia libertiana* and *Botrytis cinerea*, are likely to produce the most permanent injury.

Armillaria Root Rot.—An area in an orchard where trees have previously been killed out by Armillaria root rot is frequently chosen, through ignorance, as a convenient place for growing nursery trees. The serious danger in this procedure has been discussed by Horne (1915). It is natural that a new owner should choose a vacant place in the orchard in which to start a small nursery. For this reason care should be exercised in starting a nursery of any kind, to avoid any soil that is infested with Armillaria or other serious soil organisms.

This disease is recognized by the small, dark, cord-like structures (rhizomorphs) on or in the surface, and the felty fans of whitish mycelium under the bark. Trees may sometimes grow for some years in an infected area before enough of the roots become infected to draw attention to the trouble. In the earlier stages it is very difficult to determine which trees may be slightly infected and which may be sound (see p. 89 for a more detailed discussion of the disease).

In this state there is great danger that the trees may carry the fungus on their roots, especially in the soil of "balled" trees, to the orchard where they are to be planted.

It is evident that "balled" trees taken from the Armillaria spot, if infected only slightly, are more likely to pass inspection than trees with bare roots, because of the difficulty of seeing the symptoms. The signs of the disease are covered by the ball of earth. If an area in the orchard is known to have Armillaria in it, it is not safe to plant any trees from it, no matter how healthy they appear. If the owner himself intends to take the risk of moving such trees, they should be taken out with bare roots and the roots most carefully scrutinized for the least trace of rhizomorphs, or lesions of any kind. The safest policy is to avoid the use of any trees from such areas.

Dry Root Rot.—The characteristics of this disease have been described on page 105. The lesions usually occur on the root or on the main side roots. They have the same general characteristics as described for older trees in the orchard. In the active stage the bark shows a soft decay, but usually with less gum than in mal di gomma. Later a deeper dry rot of the bark and wood slowly develops. The wood becomes light brown. When a greater part of the wood becomes involved, the conducting vessels for sap no longer function and the tree withers and dies.

Since nursery trees may have lesions of this disease slowly developing on the roots for a considerable time before the effects begin to show in the tops, it frequently happens that trees believed to be sound are set in the orchard and only begin to show signs of decline in vigor some months later. Much time may be wasted if these trees have to be removed later. If there be the least reason to suspect dry root rot, the base of the tree

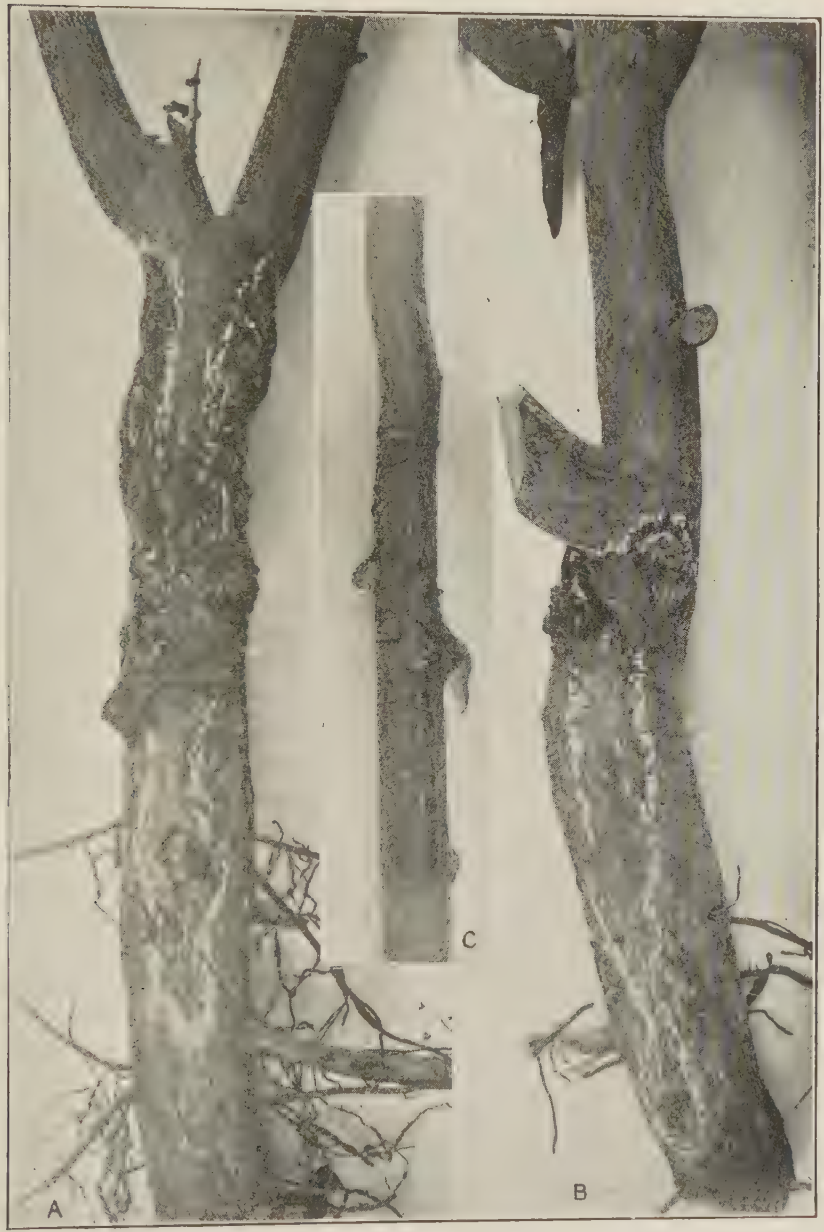

FIG. 1.—A and B, Pythiacystis gummosis on nursery stock of sweet orange, brought about by over irrigation on heavy soil, extent of lesions shown by the chalk lines; C, initial lesions on nursery stock infected during heavy rains. All showing gum exudation.

and main roots should be carefully inspected before planting for appearance of the lesion. Trees planted with bare roots are more easily inspected for such a disease. This method, however, for success in dry climates requires much greater care and supervision, as explained on page 72, than the method of planting with a ball of earth around the roots. The sour orange as well as the sweet orange is subject to the dry root rot.

This disease is favored by poor drainage, water-logged soils and lack of aeration. All nursery trees with dry root rot should be discarded.

Mal di Gomma and Pythiacystis Gummosis.—These two diseases produce lesions so similar that they cannot be readily distinguished one from the other. Bark is killed usually near the junction of the stem and main roots not far from the soil surface (Fig. 1). Sometimes it begins farther down on the roots or even in injuries above the soil. Considerable gum frequently accumulates on the bark as the disease advances. Sour-orange, trifoliate, and rough-lemon stock are more resistant than sweet orange, lemon or grapefruit.

All nursery trees with these diseases should be discarded. Their prevention consists in good drainage, care in irrigation, avoidance of piling the soil too high against the stem and avoidance of injuries. Sandy loam soils are less likely than heavy clay soils to encourage the disease. Spraying with Bordeaux mixture so as to allow the solution to wet the stems, thoroughly, especially at the soil surface and below, will also help to prevent infection.

Sclerotinia and Botrytis Diseases.—Gummosis and twig blight due to *Sclerotinia libertiana* and to *Botrytis cinerea* have been found in nursery trees, especially on trees that have been chilled or weakened by frost. They may also be favored by injuries to the bark.

These fungi may begin their attack either on the stems near the soil or on the main branches and twigs. Softening of the bark at first and exudation of considerable gum later are noted. Sclerotinia leaves the bark in a shredded condition, with formation of sclerotia frequently under it; Botrytis is less likely to produce a shredded condition but frequently develops a gray furry coating of fruiting bodies with masses of spores.

Exercising the same care as in mal di gomma will aid in the prevention of these diseases.

Scab.—In some climates scab or verrucosis tends greatly to retard the growth of young trees both in the seedbed and in the nursery. The sour orange is especially susceptible. Scabby outgrowths form on leaves and twigs. The leaves become warped and misshapen and the growth is retarded. It has been estimated by Springer (1924) that scab may sometimes cause a reduction in growth of 25 to 50 per cent in Florida nurseries.

Scab may be effectively prevented by spraying with Bordeaux-oil emulsion 3-3-50 plus 1 per cent of oil. Frequent applications should be made during the periods of formation of new leaves and shoots. Mature foliage is immune to infection.

Dodder or Cuscuta.—Dodder is a small yellow twining parasitic flowering plant belonging to the genus Cuscuta. It is common on the native plants in many parts of the world. Although it has given the most trouble in seedbeds and nurseries, it has also been seen infesting trees of considerable size in California, Florida and Mexico. This small vine-like plant twines around the twigs, adhering to them tightly. It sends out root-like processes which penetrate the bark and extract nourishment from the tissues beneath. After becoming established it throws out yellow thread-like tendrils which may soon cover the entire tree. (Fig. 2.)

The thread-like parts of the parasite should be removed and the affected branches pruned out and destroyed and a watch kept for any new development of the parasite. Plants badly infested with dodder on the native growth within or near an orchard should be cut down and destroyed by burning.

Bud Selection in Relation to Citrus Diseases.—It is well established that trees tend to transmit their characters by budding and that varieties may be propagated, true to type, usually much more readily by budding than by the planting of seeds. It has been shown by Shamel and others (1920*a*, *b*) that not only desirable types but undesirable forms are readily propagated by budding. Variations between individual twigs, or branches have frequently been found, and strikingly different forms have been propagated from buds taken from different parts of the same tree.

If characters, such as type of growth and form of fruit, can be transmitted in this way, it is most likely that susceptibility or resistance to disease may be readily transmitted by budding. Species and varieties show the truth of this theory—one species may be resistant to gum diseases, while other species, such as lemon or citron, may be quite susceptible. Many examples of this are known in other plants.

An interesting example in Citrus has been observed in connection with decorticosis or shell bark of lemon trees. The Eureka lemon variety is usually much more susceptible to decorticosis than the Lisbon variety, the disease appearing at an earlier age, and spreading more rapidly after starting on the trunks of the former than on the latter.

Going a step further, it has become evident that there are certain strains within a variety which differ in their susceptibility or resistance to disease. This is exemplified by certain strains of the Eureka variety, which are much more susceptible than other strains under exactly the same conditions. A striking case of this kind has been observed in which a set of Eureka lemon trees began to show the symptoms of the disease at the age of eight to ten years, while most Eurekas under the same conditions were free until they were fifteen to twenty years of age. On investigation it was found that these extremely susceptible trees had been propagated from buds taken from individual trees showing high yields but which were suffering from very severe cases of decorticosis on their

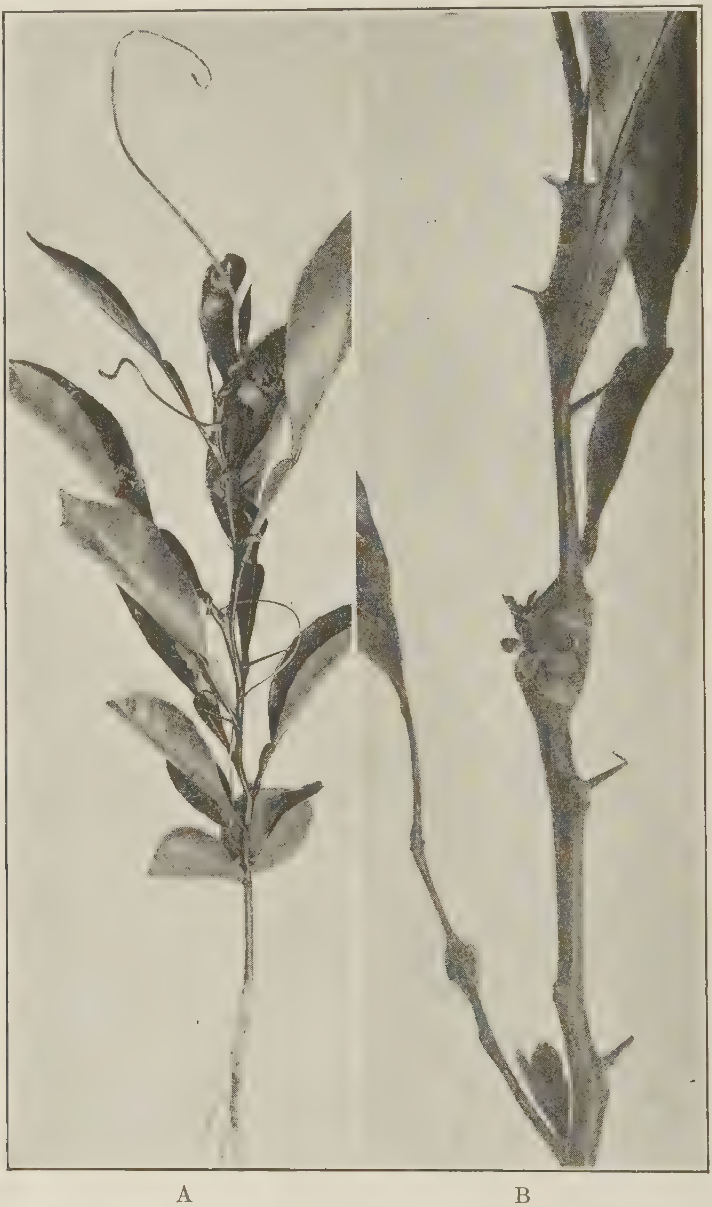

Fig. 2.—Dodder, a parasitic flowering vine, *Cuscuta* sp. shown in A, beginning to entwine a seedling sour orange plant, and the later effect shown in B, as gall-like swellings on the stems. B, photo by C. O. Smith.

trunks and large limbs. In fact, the trunk showed evidence of a repeated renewal of bark, at two or three consecutive periods, as a result of this disease.

Moreover, a second block of trees planted from the same source in another locality also contracted the disease at an early age, while at the same age all the blocks around it from other sources did not show it.

Not only in decorticosis but in other diseases and abnormalities there seems to be every indication that transmission may take place by means of buds.

It is, therefore, of great importance from the standpoint of transmission of resistance to disease, as well as from other considerations, that great care be exercised in the selection of buds from healthy trees that show no tendency to disease in any of their parts. While this may not insure resistance, since certain individual trees may have escaped disease, even though not inherently resistant, such care, nevertheless, increases the chance of obtaining resistant trees. In taking buds for new trees great care should always be exercised to avoid getting these buds from any trees showing the least tendency to disease. In order to insure greater stability in resistance, one should also avoid as far as possible taking buds or grafts from trees showing a tendency to great variation within themselves.

Budding and Grafting in Relation to Citrus Diseases.—In budding or grafting Citrus trees, to avoid the transmission of diseases or to avoid infection and development of diseases, especially at certain seasons or in certain climates, great care should be exercised to have clean tools and clean material at all times. When this budding and grafting are done in very dry weather or in dry climates, the danger of infection is usually not so great as in moist weather or in damp climates. The spores of fungi that readily infect wounds are sometimes very abundant and it may be necessary under these conditions to use disinfectants. If disinfectants become necessary, the surface of parts to be budded or grafted may first be rubbed with 95 per cent alcohol and allowed to evaporate quickly just before the tissue is cut. If a stronger disinfectant becomes necessary, mercuric cyanide, 1 part to 1000 parts of a watery solution containing one-fourth of its volume denatured alcohol, or an equal strength of mercuric chloride, or a mixture of both, may be used, for disinfecting the surface of bark and tools. The parts, after disinfection for five minutes, may be washed in boiled, cooled water.

Planting in Relation to Citrus Diseases.—The manner and the care with which Citrus trees are planted may have an important influence in the avoidance of certain diseases. Clean tools that have not become contaminated in the digging out or cutting away of diseased trees should be used. To make certain that no diseases are transmitted in this manner, the tools should be carefully cleaned of all adhering soil and disinfected with any good fungicide that happens to be at hand, such as mercuric cyanide, 1 to 1000; 2 per cent formalin or Bordeaux mixture.

Care should also be taken to avoid any unnecessary mechanical injuries to the roots and trunk in planting trees. When the roots or branches are cut off, smooth cuts should be made. If these are more than an inch in diameter, it is well to disinfect them with some good fungicide and then paint them with white lead paint, benzine-asphalt paint, a safe carbolineum or some other good covering. Injuries to the lower trunk and roots may readily become infected with brown rot gummosis, mal di gomma, Sclerotinia or Botrytis gummosis, especially on heavy soils.

It is also important to avoid too much exposure to the sun or to drying winds in transplanting. To avoid sunburning, the bark of the stem should either be protected with tree protectors or the parts above the ground should be whitewashed.

In transplanting trees two methods are generally used; one is to remove the trees with a mass or ball of earth about the roots, and the other is to remove the trees with the roots laid bare. Each method has its advantages and disadvantages. The removal with bare roots is better suited to moist than to dry climates. In removing the trees with a ball of earth around the roots the fibers are less likely to become dried out. The disadvantage of this method, however, is that in case a disease is already present in the roots in the nursery it is not readily detected, and the disease may be taken with the tree to the orchard. Also, if the soil in which the tree is placed is very different from that of the ball, it may either hinder sufficient water from getting to the roots or cause too much water to be taken up. Sometimes this ball remains too dry or too wet, encouraging certain root rots. There is also a chance of transmitting the Armillaria root rot from the nursery (see p. 66). In case the trees are transplanted with the roots laid bare, one may more easily detect any diseases already present.

This bare-root method, however, requires for success much greater care than the other, especially in dry weather. In certain climates this drying out may take place so very rapidly that the fibrous roots will be killed in a short time. It is therefore necessary that the roots be kept constantly moist when they are being moved. If the ends of roots are severely injured by drying out they will later be more subject to the attack of certain soil organisms before they have become established.

Sometimes trees are dipped in certain disinfectants or fungicides when they are transplanted. Care should be taken that these disinfectants or fungicides are not so strong as to injure the bark at the base of the tree and that they do not run down freely on the tender roots.

In setting out trees they should not be placed too deeply in the soil. Deep setting often encourages such diseases as Pythiacystis gummosis, mal di gomma and root rots. The trees should be set so that the junctions of the trunk and main roots are just below the surface of the soil and so that as much of the bark of the trunk as possible is exposed to the air. Such precautions are especially necessary with susceptible stocks and even with resistant stocks if these have been budded low. The base of the trunk or the bud union is usually the most susceptible region for the start of various gum diseases.

In irrigating trees that have been recently set out, it is, of course, necessary to get the water fairly close to the trunk, but on heavy soils special care should be taken not to allow excessively wet soil to be in contact with the bark too long at a time or to allow the soil to be water logged around the trunk of the tree for a number of days.

Stakes which are used in tying the trees when they are first transplanted should be carefully removed later, and not broken off when they have served their purpose; since disease-producing fungi may start on such pieces left in the ground at the base of the trees. The roots in growing may enclose these stakes, which may then become sources for the start of root rots and certain forms of gummosis. Pieces of string or wire used in tying around the trees, or in attaching labels should be either carefully removed or watched from time to time to prevent them from injuring the expanding bark and thus opening up the way for certain root and trunk diseases.

Many of these things herein mentioned may seem obvious and trivial, but experience has shown that many good Citrus trees have been injured or have contracted serious diseases through carelessness in these small matters.

Irrigation in Relation to Citrus Diseases.—As will be brought out later in the discussion of the individual diseases, irrigation practices have a very important influence, both directly and indirectly, upon the severity and development of certain Citrus diseases, especially on the diseases that attack the roots and base of the trunk.

In a more indirect way extremes of moisture in irrigation may have an influence on diseases in the top of the tree by weakening the resistance in the branches, leaves and fruit.

One of the most striking examples of the influence of too much water in irrigation at the base of the tree is that of the Pythiacystis gummosis and mal di gomma. The chief contributing conditions for the occurrence of these two diseases is excessive moisture, for considerable periods of time, at the base of the trunks and larger main roots. This relation is so important that if proper care is taken to keep the soil pulled away from the base of the trunks and large main roots and to keep these parts from becoming wet over long periods of time, these diseases are almost entirely prevented without the use of any other means of control.

The brown rot of the fruit, due to the same fungus which causes the Pythiacystis gummosis, is also dependent upon excessive water. It has been found that, in order that the fungus may develop into a condition for infection, there must be free water in or on the soil; during periods of heavy rainfall or irrigation the fungus grows to the surface and develops its swarm spores in the water. Subsequent heavy rains splash these spores against the low-hanging fruits and they become infected. In regions where irrigation is practiced, if an excessive irrigation precedes a rain this may also contribute to the occurrence of brown rot.

Excessive irrigation or water logging may also have an influence on Armillaria root rot, Sclerotinia root rot and other forms of root diseases. On certain types of soil, such as those underlaid with hardpan or a sandy soil underlaid with coarse gravelly subsoil, irrigation practices may have a bearing on exanthema as discussed later (p. 243). The extremes of water conditions appear to be contributing factors.

Irrigation also has an important influence on alkali injury, especially if the water contains large amounts of the alkali salts. The irrigation with good water after alkali has accumulated may on certain soils be carried on in such a way as to wash the alkali salts down below the feeding roots.

On certain soils, especially the heavy clay or adobe type, too frequent or excessive irrigation may cause water logging and lack of aeration. The fibrous roots are caused to decay and this, in turn, has a serious effect upon the whole tree, making it more subject not only to non-parasitic diseases such as mottle leaf, chlorosis, etc., but also to anthracnose, Diplodia gummosis and other types of fungus diseases of stems, leaves and fruit.

Irrigation practices may also have an important effect upon the occurrence of endoxerosis or internal decline, as will be brought out more fully under the discussion of that disease (p. 424). An excess of water, as stated above, may cause the fibrous roots to rot and the tree will subsequently not get enough water to its leaves and fruit, even though there is sufficient in the soil. Too little water may accomplish somewhat the same results by drying out the fibrous roots. It is therefore important not only from the standpoint of the growth of the tree itself, but from the standpoint of the attack of diseases, that the proper irrigation practices be carried out.

The best practice will vary according to the climate and type of soil. Four points that need to be especially watched in relation to disease are: (1) avoidance of excessive water next to the trunk; (2) avoidance of too long furrows; (3) avoidance of water having too high a salt content; and (4) the providing of good drainage and aeration.

Aeration of the Soil in Relation to Disease.—Although little investigation of a definite nature has been made as to the relation of aeration to root diseases, this factor is no doubt an important one. A supply of air in the soil, from which oxygen may be obtained, is necessary for the roots of most plants. If oxygen is lacking, roots will be killed or weakened so that they subsequently become a prey to attack by organisms. Experience and observation would indicate that adequate air in the soil is very important for Citrus roots.

In the process of respiration the roots as well as other parts of the plant take in oxygen and give off carbon dioxide. The carbon dioxide gas unites with the water, making carbonic acid. The carbonic acid from this source as well as from other sources attacks the insoluble mineral elements of the soil. The type and condition of the soil have a great deal to do with amount of air available. In compact clay soils the air spaces are very small. In loose sandy soil they are comparatively large.

In an experiment by Hutchins and Livingston (1923) with a certain clay loam soil it was found that the oxygen-supplying power of the soil was 1000 to 1300 cubic millimeters per hour when moistened as for good growth of plants, 590, or one-half as much, when quite wet and only 20, or about one-sixtieth as much, when wet and packed.

Aeration is probably an important factor in many forms of Citrus root diseases. Roots are killed or injured by water logging of the soil. The water completely fills the air spaces, crowds out most of the air and prevents other air from entering. Many parasitic organisms probably require less oxygen than the roots and can grow well in watery solutions that would injure the roots. Even if the roots are not completely killed by the water logging, they may become so weakened as to become less resistant to attacks by the root-disease organisms. Roots may also lack oxygen when the soil becomes too compact in certain layers so that air cannot pass readily through it.

There is also a possibility of the other extreme, *i.e.*, too much air in certain loose types of soils. The air may actually become excessive, so that under certain conditions such rapid chemical changes may take place as to lead to malnutrition, as in the development of exanthema in Florida, when sandy soils are stirred too much during certain seasons.

Aeration may be obtained by plowing, by drainage, by proper irrigation, by incorporation of bulky organic material, etc. Excessive aeration may be partially prevented, when necessary on soil types that are too loose, by less frequent or more shallow cultivation.

Cultivation in Relation to Citrus Diseases.—As in almost every operation that has to do with the proper growing of Citrus trees and development of fruit, cultivation, if properly done, has a beneficial effect, indirectly at least, in rendering the trees more resistant to many of the diseases but when improperly done it may have a very harmful influence in encouraging the development of certain diseases.

Some of the ways in which cultivation may be beneficial in lessening diseases are: (1) by bringing about aeration, so that the roots may have a vigorous development, through which the tree is more normally fed; (2) by producing conditions that will allow the irrigation water to penetrate to the roots properly; and (3) by preventing the formation of plowsole and baking of the surface.

Some of the ways in which the operations in cultivation may actually increase or influence the occurrence of diseases are: (1) by producing injuries to the main roots and trunk through which the gum disease and root rot fungi may enter, causing death to the bark and in severe cases to the whole tree; (2) by puddling the soil when it is stirred in a wet condition; (3) by producing excessive aeration on very loose types of soils subject to exanthema. While loosening the soil around the trunk may be necessary in many cases, it should be done with care in order to prevent injuries into which parasitic soil fungi or wound parasites may enter. As in all other operations, cultivation must be carried on with judgment in accordance with the climate and other conditions. With an understanding of the indirect effects upon disease occurrence of too much or too little cultivation, or other accompanying practices in a particular orchard or locality, growers may do much to keep their trees in a vigorous condition.

Frost Protection in Relation to Citrus Diseases.—The injury produced by frost, even on the tree itself or on the fruit, often renders them much more susceptible to diseases of various kinds. The injury may be very slight and scarcely visible and yet it may induce in the plant tissues conditions favorable for disease occurrence. It is well known that the chilling of plants, even at temperatures above those that actually kill the tissues, may render these plants subject to attack by certain fungi.

In Citrus trees a number of fungi that do not ordinarily produce much damage may, by first entering frost-killed tissues, advance later into the live tissue. Fungi such as Sclerotinia and Botrytis are of this nature. Many cases have been observed of these fungi spreading into the sound tissue of Citrus bark after they have apparently gained entrance by way of wounds or dead areas.

Lemon fruits that have been slightly impaired internally by frost and yet not sufficiently to cause them to be rejected in picking for market, may become quite susceptible to the entrance of fungi, such as Alternaria, Phomopsis, Diplodia, Dothiorella, etc. It also appears that trees which have received a severe shock from frost produce fruit the following year more subject to some of the physiological diseases, such as red blotch, membranous stain, internal decline, etc., than fruit from trees not so affected. Procedure for the treatment of frosted trees will be found on page 202.

Fertilizing in Relation to Citrus Diseases.—It is well known that the kind and amount of fertilizers have some influence, either directly or indirectly, on the occurrence of diseases in general. It has been shown that pear blight is more prevalent on trees that are growing rapidly on cultivated soils than on slower-growing pear trees growing without cultivation.

As regards Citrus trees, observations have indicated that the kind of fertilizers have a considerable amount of influence on certain diseases, although the information at hand is mostly of a general nature. Orange and lemon trees that have had an inadequate amount of fertilizer, especially nitrogen, are apt to have dead branches and poorly nourished leaves which appear to be more subject to the secondary attack of the anthracnose fungus, the Diplodia fungus and other organisms. An application of the right amount of nitrogenous fertilizer following treatment for mal di gomma or other bark diseases may hasten recovery. In Florida in case of exanthema, on the other hand, overfeeding with certain kinds of fertilizers has proved to be a real danger. On some soils the use of too high percentages of organic nitrogenous fertilizers, such as blood or tankage, appears to have a marked influence in aggravating this disease.

Fertilizers, together with the chemical make-up of the soil, apparently have a very important influence on the development of chlorosis and mottle leaf. As will be brought out later, compounds such as calcium carbonate that have a high alkaline reaction may so act on certain soils as to prevent the trees from obtaining either sufficient iron or calcium and therefore produce chlorotic leaves and stunted growth. It also seems to be likely that the application or withholding of any fertilizers that tend to prevent the tree from getting adequate supply of calcium, especially when the potassium content is high, will have an influence on producing mottle leaf (p. 336).

The application of stable manure or bulky organic materials on certain soils may have a beneficial influence in counteracting some of the effects just mentioned. This material, by setting up decomposition and the liberation of carbon dioxide, may enable the plant to obtain more adequate supplies of both calcium and iron, even in soils that have considerable alkalinity.

These varied influences of fertilizing emphasize the importance of observing the growth conditions on each particular soil so as to avoid overfeeding on the one hand and undernourishment on the other, since both extremes may render the trees susceptible to certain diseases.

From the disease standpoint, the aim of fertilizing is not only to preserve the future health of the tree but at the same time to produce large crops of sound fruit that will be resistant to diseases.

Cover Crops in Relation to Citrus Diseases.—Cover crops, in so far as they improve the condition of the soil and provide proper fertilizer, may help to increase resistance to many of the diseases. Their presence may, however, have an influence in increasing the problems connected with certain diseases. This harmful effect, however, is usually not sufficient to cause cover crops to be abandoned, except temporarily in some cases.

During a very moist year in California a cover crop may encourage the cottony rot fungus, *Sclerotinia libertiana*. The cottony rot first develops on the roots and stems of the cover crop, and its increased abundance may cause a considerable loss when the fruit is picked and taken to the packing house. A discussion of some of the methods by which it may be prevented will be found on page 384. Cover crops and tall weeds appear also in very moist seasons to have some influence on the brown rot due to *Pythiacystis citrophthora*. When tall weeds are growing under the trees and up through the low-hanging branches, they appear to furnish means by which Pythiacystis spores can get to the fruit more readily. If the cover crop is very thickly matted over the soil and is without tall weeds, however, it may actually prevent the splashing of the spores to some extent. The growers, as a rule, will prefer to have some loss from increased rot rather than do without the beneficial effects of cover crops.

Pruning in Relation to Citrus Diseases.—Pruning may be either beneficial or harmful in relation to Citrus diseases, depending on how and under what conditions it is performed. In so far as it may eliminate the diseased parts and cut down the source for infection by microorganisms, it may prove highly beneficial; on the other hand, pruning may, if carelessly done, actually increase or spread certain diseases or render the tree less resistant.

Pruning to Eliminate Diseases.—In certain diseases, such as melanose and stem-end rot, the causal organism is known to produce its spores in great numbers on the dead twigs and branches of the tree. It is therefore helpful in the control of diseases of this kind to prune out these dead parts. In cases such as psorosis, where severe lesions occur on branches, these branches may often be cut out and the disease thus eliminated. It is important, after pruning trees to eliminate definite diseases on the branches, that the pruning tools be disinfected before they are used to prune healthy trees. The spores of certain fungi may readily be carried on the pruning tools. It is also important in many cases where the cuts are large, to disinfect them and subsequently paint them, or to paint them with something that will at the same time disinfect and cover them.

Avoidance of the Spread of the Disease in Pruning.—In pruning for other purposes, such as rejuvenating the tree or making the tree more productive, or in pruning after frost or other injury, it may be possible at times to spread diseases or to open up the way for their greater development. As a general rule, in pruning Citrus trees the cuts should be made so as to leave no projecting stubs. A branch should be cut off back to the fork. If the cuts are an inch or more in diameter, they should be disinfected and painted.

When large branches are taken out, in grafting or budding to other varieties, special care should be taken to protect the cut places and the bark on the branches that have not been previously subjected to the rays of the sun. Large cuts should be carefully disinfected and covered and exposed portions should be protected from sunburning by whitewashing.

It is important also to have good sharp tools that will make clean cuts free from rough or jagged edges. If these cuts are made in a moist, cool season of the year or in regions which have a moist climate, there is much more danger from the wood-rotting microorganisms than if they are made in the drier seasons of the year or in climates that are rather dry and hot, such as the interior valleys of California. The best means for caring for these cuts is to disinfect them with a solution, such as mercuric cyanide, 1 to 1000 parts as previously mentioned, or the same strength of mercuric chloride, 4 per cent formalin, or a safe carbolineum, and let them dry from one to two or three days, depending upon the dryness of the air, and then paint them with some good air-tight covering, such as asphalt paint or white lead paint. Experience has shown that an immediate application of a waterproof covering before disinfection or before drying out often encourages rather than hinders wood rots.

PART II

ROOT AND TRUNK DISEASES

INTRODUCTION

On the roots and the trunk are found some of the most serious and destructive of the diseases to which Citrus trees are subjected. This is to be expected, since the base of the trunk, and especially the roots, are the parts through which the attack by disease is most apt to be fatal to the entire tree. In countries with dry climates where irrigation is practiced, as in most parts of California, diseases of this type are especially important. In such climates it is at the roots and base of the trunk that moisture is apt to be most suitable for propagation of microorganisms. The growing branches, leaves and fruit are subjected most of the time to a dry atmosphere not so conducive to the attack of microorganisms, such as the fungus parasites. In more humid climates twig, leaf and fruit diseases are relatively more severe.

The complete prevention or successful treatment of root and trunk diseases is of the highest importance. In the top of the tree severe damage or even death to small branches, leaves or fruit is but temporary, since new ones may be developed again, provided the roots and trunk are kept sound.

These trunk and root diseases in Citrus are of two general types: (1) those which primarily affect the bark only and seldom injure the wood; and (2) those which destroy the wood and only indirectly the bark. Examples of the bark destroyers which kill the tissue through to the wood are Pythiacystis gummosis, mal di gomma, Botrytis gummosis and bark rot; examples of those which typically kill only the outer layers of bark, allowing new tissue to build up at the cambium, are psorosis of oranges and decorticosis or shell bark of the lemon. Examples of diseases primarily wood destroyers or both are Armillaria root rot, Rosellinia root rot, dry root rot and the wood rots or heart rots, which last are brought about by a variety of organisms, such as *Schizophyllum commune*, *Polystictus versicolor*, species of Stereum, etc.

In addition to the diseases due to microorganisms, certain of the effects due to insects and other animals and to physical and chemical injuries are briefly discussed in so far as these effects might be mistaken or confused with those due to microorganisms. In most of these diseases more than one factor is operative in bringing them about. The attack of many microorganisms is aided in a large measure by the physical conditions of the environment as well as by the physiological condition of the host plant. Wounds from animals or wounds received from cultivation, injuries from extremes of temperature and extremes of moisture often precede or open the way for the attack of microorganisms. Many of these relations are more fully discussed later under the specific diseases.

In Part II the diseases are arranged for convenience of reference into three groups: (1) diseases primarily affecting the roots; (2) diseases primarily affecting the crown roots and the base of the trunk; and (3) diseases affecting the trunk and main limbs. Where a disease would fall into more than one group, it is placed where it usually appears to be most destructive, with repetitions in the key for more complete identification.

Key to Root and Trunk Diseases

Page

I. Lesions which usually result first in the death of the outer and inner layers of the bark, the cambium region and sometimes the wood:

A. Located in the roots:

1. Cord-like brown growths (rhizomorphs) resembling roots on or within the surface of the bark, and with white to pinkish-cinnamon, fan-shaped mycelial plates under the bark; usually also a wet rot of the woody cylinder—
   Armillaria root rot 89
2. Wefts of brown mycelium on the surface of the larger roots, with white mycelium in stars or fans under the bark. With black thin carbonaceous crusts (stroma) just below the surface on old roots, and sometimes dark olive-green mycelium on the trunk above the soil surface. Mostly in forest clearings in moist tropical climates—
   Rosellinia root rot 98
3. Black carbonaceous crust-like layers at the foot of the tree following injury from too much water at the roots; Porto Rico and India—
   Ustulina fungus 112
4. Bark-like portion of the root showing a shredded appearance. Larger roots showing a white cottony mycelium and frequently black sclerotial bodies within or under the cortex—
   Sclerotinia root rot 103
5. Dead roots covered with white felt-like coating of mycelium which frequently extends also on to surface of the live bark of larger roots or base of trunk. On heavy soils that are subject to water injury—
   Poria fungus 109
6. Beginning as moist decay of the bark-like portion usually on larger roots some distance below the surface of the soil, gum usually small in amount or inconspicuous. Difficult at this stage to distinguish from beginning stage of mal di gomma or Pythiacystis gummosis. Later, involving the wood as a hard, brown, dry decay, usually with less gum than in No. 7 (see also *B*-2)—
   Dry root rot 105
7. Beginning a short distance below the surface of the soil on larger roots or trunk, usually with more gum formation at the cambium than in No. 6. Cambium region mineral brown to fawn in color. Spreading more rapidly upward to the crown and base of the trunk with copious gum formation when active (see also *B*-1)—
   Mal di gomma 146
   Pythiacystis gummosis 125

PAGE

8. Sloughing off of fibrous roots with death of larger roots later, following excessive irrigation and water logging of soil—
    - Water injury 109
9. Individual roots appearing to die rather suddenly and dead strips of bark and wood appearing on the trunk with effects on certain branches
    - Gas or oil injury 120
    - Fumigation injury 155
    - Lightning injury 315
10. Grooves or irregular furrows where bark has been eaten away by a footless white grub about ½ to ¾ inch long. Where very numerous, resulting in girdling and death of the roots. Cuba—
    - Blue-green beetle 118

B. Lesions found at or beginning usually near the junction of the trunk and main roots:

1. Beginning usually at or below the soil surface in dry climates, sometimes beginning also above in moist climates. Bark killed through to wood; at first remaining firm, not soft. Cambium region becoming reddish brown to fawn or light brown in color with a surrounding gummous zone of chamois to slightly brownish yellow. May spread upward on base of trunk with copious gumming when active. Ill-smelling odor from secondary decay, especially below soil surface (see also *A*-7)—
    - Mal di gomma 146
    - Pythiacystis gummosis 125
2. Somewhat similar to No. 1 at first, but usually beginning deeper on the roots, and showing less gum and not, as a rule, extending far above the soil surface and showing slight or no gum formation, also causing dry rot of the wood. Often associated with the forms of gum diseases in No. 1—
    - Dry root rot 105
3. Bark eaten away from portions of the main roots and base of trunk, usually with small islands or patches of rejuvenated tissue scattered over it and fibrous roots growing out from the injured edges—
    - Rodent injury 154
4. Beginning with softening of the bark through to the wood, and later resulting in a shredded condition, with or without black bodies (sclerotia) in or under it. Gum sometimes copious, when disease is active. Frequently following periods of frost injury (see also *C*-1)—
    - Sclerotinia gummosis 153
5. Long dead strips of bark usually from the base of a root upward and sometimes downward, involving some wood tissue underneath—
    - Fumigation injury 155
    - Gas and oil injury 120
    - Lightning injury 315

C. Lesions beginning usually on the trunk or larger branches above the soil surface:

1. Lesions with bark at first soft and easily punctured, and with considerable gum formation. Usually starting in wounds of various kinds or in injuries from frost or sunburn:
    - *a*. Bark becoming shredded with formation of large sclerotia under it—
        - Sclerotinia gummosis 153

Page

b. Bark not becoming shredded and sclerotia usually absent. Gray coating of spore-bearing bodies may be present on surface in moist, cool air—
Botrytis gummosis 183

2. Bark becoming dead to the wood in small patches not so soft as in No. 1.
a. Fusoid gum pockets often formed by dissolution of inner bark tissue and wood, forming elongated cavities and grooves chocolate brown next to the cambium. Wood discolored for short distances inward—
Dothiorella gummosis 191

3. Bark killed either over small patches, as in No. 2, or more extensively, as in cases of Pythiacystis gummosis. Differs from the latter in extending deeper into the wood tissues and often becoming a wood rot—
Diplodia gugmmois 190
Dothiorella gummosis 191
Gummosis associated with Torula 194

4. White foam or froth exuding from cracks in the bark of the trunk and large limbs, followed by the death of the surrounding tissue and finally the death of large branches or the entire tree. On mandarin and Satsuma oranges in the Orient—
Bark rot 171

5. Small portions of bark killed to the wood surrounded by scaling of outer bark over extensive areas with formation of gum. Stain frequently seen in the wood—
Later stages of psorosis 158

6. Resulting in small or large patches or strips of dead bark on the trunk or large limbs—
Frost injury 201
Sunburning 201
Bark spot of Brazil 193
Fumigation injury 155
Lightning injury 315

II. Lesions usually involving the wood first and sometimes the bark later:

A. Rot usually proceeding from stubs or wounded portions of the tree:

1. Hard, firm, dark decay extending rapidly from ends of large stubs—
Heart rot due to Diplodia 196

2. Usually lighter in color, finally becoming soft—
Wood rot due to Schizophyllum 196

3. Soft and punky decay of wood often accompanying or following (1) and (2)—
Wood rot due to Polystictus, Stereum, Fomes, etc 196

B. Concavities covered for the most part by live normal bark on the trunk or branches with wood variously affected underneath:

1. Small amount of gum oozing to surface through a crack in the live bark of the concavity. Masses of gummy granulated tissue under the bark, with deeper underlying layers of wood impregnated with a cheesy, gummy substance—
Concave gum 192

2. Cup-like depressions usually smaller than (*a*), without gum on the surface, with a core of ochraceous-salmon-colored tissue within layers of wood—
Blind pocket 193

PAGE

C. Tunnels in the wood usually accompanied by dust or frass near stubs or dead areas—
    Borers.......... 196

III. Lesions usually resulting in the death of outer layers of bark or cortex only, the inner layers and cambium remaining alive, although often involved in gumming and formation of small localized gum pockets or stained tissue:
  A. Located on the roots:
    1. Small superficial irregular grooves on the surface, injuring only the outer layers of tissue—
      Fuller's rose beetles.......... 118
    2. Small, thin scales of bark short distances below the surface of the soil often mistaken for psorosis—
      Fumigation injury.......... 155
    3. Definite thicker scales on larger roots of trees badly affected with psorosis on the trunk. Only rarely found on roots (see *B*-1)—
      Psorosis.......... 158
  B. Located on the trunk or larger branches:
    1. Beginning either with irregular dead scales of bark ¼ to 1 inch in diameter with live bark underneath or with small pustules or pimples under which are brown specks. Resulting later in gum formation at the cambium and on the surface; and resulting in extensive areas of scaly bark. Rarely on bark less than 6 years old—
      Psorosis.......... 158
    2. Beginning as oval glazed spots chestnut or auburn in color, usually on branches or twigs nine months or two years old. Later showing extensive areas of scaling on trunk and large limbs, much as in psorosis—
      Leprosis or nailhead rust.......... 231
    3. Much like the last but with a carbonaceous belt of pustules in a sharply defined furrow encircling the spots; occurring in Paraguay and Argentina—
      Lepra explosiva.......... 240
    4. Cracking and shelling of outer bark on lemon-tree trunks or larger limbs of considerable age. Usually forming long vertical strips. New bark building up underneath. Gum absent or occasionally formed on the surface. Often accompanied by Botrytis, Diplodia or Dothiorella gummosis—
      Decorticosis or shell bark.......... 176
    5. Bark slightly peeling on one side of tree with normal bark underneath—
      Slight cases of sunburning.......... 201
        or
      Frost injury.......... 201
        or
      Fumigation injury.......... 155
    6. Small depressions as if outer bark had been eaten away; and usually with gum exuding—
      Fire ants.......... 194

IV. Superficial markings, abnormalities or general effects:
  A. Located on roots:
  1. Fibrous roots irregular, appearing as if swollen; a tendency for earth to cling tenaciously to them and for bark to loosen from woody cylinder even when not dead—
    Citrus nematode.......... 113

Page

2. Sloughing and death of fibrous roots, especially on heavy wet soils—
   Water injury 109

B. Located on trunk and branches:

1. Abnormal swellings and production of tissue on trunk or branches—
   Sphæropsis knot 322
   Galls 326
2. Abnormal production of swollen branches in clusters—
   Witches'-broom 327
3. Flat patches of gray-green to reddish-gray, thin, paper-like or crusty growths on the bark surfaces—
   Lichens 200

CHAPTER VIII

ROOT DISEASES

ARMILLARIA ROOT ROT

Armillaria root rot due to the fungus *Armillaria mellea* is a serious disease on Citrus in certain parts of California and Australia. It has also been mentioned by Comes (1891) in Italy and Mayet (1891) in Corsica. As far as known, it has not been reported as an important disease of Citrus in any other countries. The disease is known by various other names, "oak root fungus," "fungus root rot," "mushroom root rot" in California and "honey fungus" in Australia. The same fungus attacks the roots of many plants. Few diseases affect so wide a variety of plants as this one. Almost any woody long-lived root appears to be subject to attack. Some trees, however, are much more susceptible and more rapidly killed than Citrus. Certain deciduous fruits, such as apricots or peaches, are especially susceptible. The fungus lives on the decaying roots of native trees from which it may spread in the soil to Citrus roots.

W. T. Horne (1910, 1912, 1914, 1915*a*) has made a special study of this disease under California conditions. Barrett (1918) and Fawcett have made observations as to its effect on Citrus in California, and Hendrickson (1925) recently on deciduous fruits in California. In Australia it has been reported as serious on Citrus by Darnell-Smith (1914), Birmingham and Stokes (1921).

Symptoms.—Signs of the presence of the disease on the above ground portion of the tree are usually not apparent until the fungus has become well established. The effects in the top may show either as a sudden wilting and collapse without any marked previous symptoms, or there may be a more gradual deterioration manifesting itself in yellowing and dropping of foliage over the entire tree or a definite part of it. An extra heavy crop may be produced. One side or limb of a tree may show signs of deterioration while the remaining portion is normal. These symptoms in the top are not unlike those produced by other root troubles, such as mal di gomma, dry root rot, water injury, etc., so that it is usually not possible to diagnose the disease with certainty without looking for the signs or the presence of the causative fungus. Beginning as a puffing or swelling of the bark on the roots, the fungus later shows white, felty fan-shaped growth under and in the bark, cord-like purplish-brown rhizomorphs on the root surface and light-brown toadstools showing above ground.

The Toadstools.—The most conspicuous characteristic of the fungus (although least often present) is the light-brown toadstool clusters coming up at the base of the tree during the late fall and early winter months. These clusters will be found to be above an affected root or crown. These toadstools, according to Horne (1912), are light-tan color above, varying considerably according to dryness of the atmosphere, usually with tiny brown scales on the top. The lower surface of the cap is white or dull white, and the white spores dropping downward often form a white powdery appearance on the ground. A delicate ring usually occurs on the stalk below the cap. (Fig. 3.) The toadstools last only a short time. They turn dark and soon become infested with larvæ of gnats, which reduce them to a disintegrating mass.

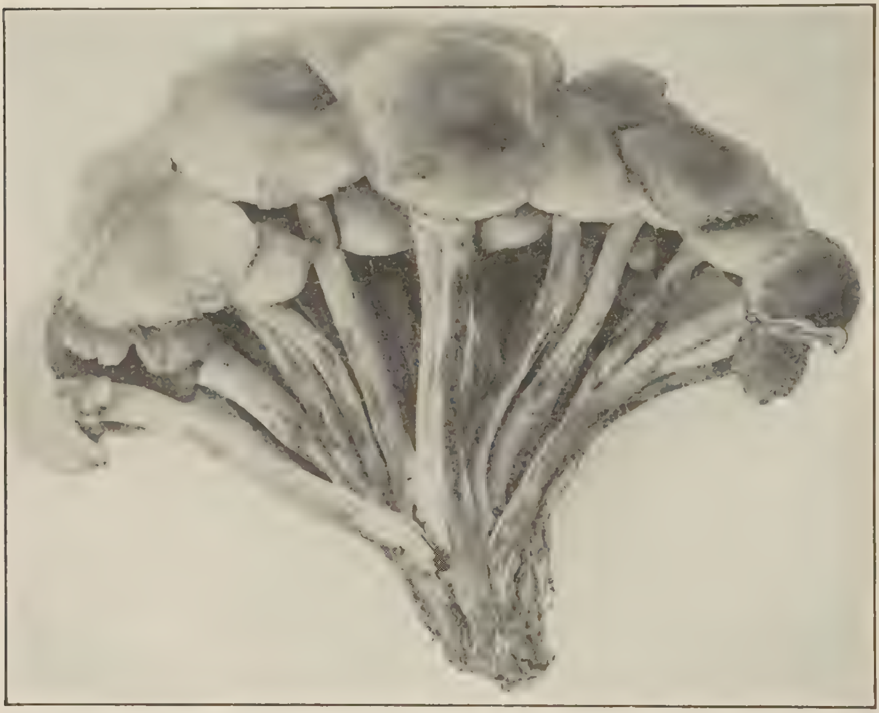

FIG. 3.—Toadstools of the *Armillaria root rot fungus Armillaria mellea.* *(Cal. Agr. Exp. Sta.)*

The Rhizomorphs.—On the surface of the affected and rotted roots and also extending out short distances from them, will be found cord-like, purplish-brown growths. These look like small roots, the resemblance giving rise to the suggestive term rhizomorphs, root forms (Figs. 5 and 7.) These may grow for some distance through loose soil, but in firm soil the distance is limited. They differ from roots in being smooth and shiny when fresh and they branch differently. As pointed out by Horne, the rhizomorph if twisted in the fingers is seen to be composed of an outer, brittle shell, and a light-colored, tow-like center, while true roots have a woody core. A rhizomorph consists of a bundle of fungus threads, the outer layer of which has hardened into a shell. If a tip of an advancing rhizomorph reaches a susceptible root, the bark is penetrated and a white fan-shaped mycelium is formed underneath, resulting in the rapid death of the invaded portion. Rhizomorphs are not always easily found even when the fan-shaped mycelium is present. It is possible that they are absent or disappear in competition with other organisms under certain conditions.

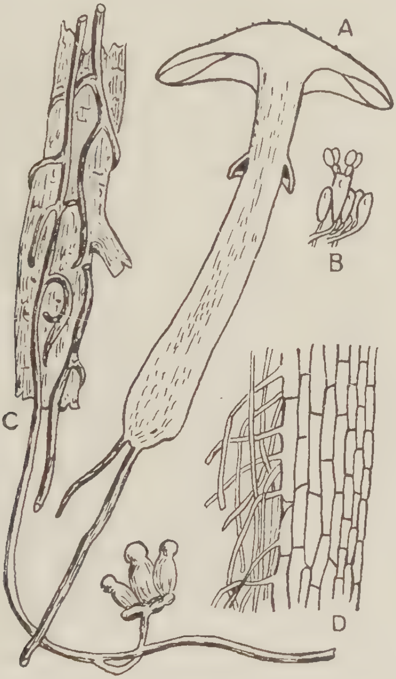

Fig. 4.—*Armillaria mellea.* A, Toadstool; B, section of gill of the toadstool highly magnified showing spores on one of the basidia; C, portion of a dead root showing branching strands or rhizomorphs, and a cluster of young toadstools springing from one strand; D, section of a rhizomorph from the outside to the center highly magnified. (*After Massee from Darnell-Smith.*)

Fan-shaped Mycelium.—An invariable sign of the disease is the fan-shaped mycelium, white to light-pinkish cinnamon within or under the bark (Figs. 5 and 6). The tissues of the bark are invaded by this white or creamy-white mycelium. When the bark is pulled away from the root, this mycelium appears as a flat, spreading, felty mat or sheet between the bark and the wood. It is marked by lines of greater thickness giving the appearance of a fan, or a series of fans (Fig. 5). The bark and wood become watery and soft. At the upper margins of the invaded bark, when it extends above the soil on the crown or trunk, there is often a copious gum formation. The odor of pure Armillaria decay is a sharp mushroom smell rather than that of "sourness" or "putrefaction." The odor differs markedly from that usually associated with mal di gomma, dry root rot or Pythiacystis gummosis. One or more of the latter diseases, however, are frequently associated in the same orchard with Armillaria root rot. Other kinds of toadstool fungi may invade the bark of roots killed by some other cause and form felty mycelium. It sometimes requires considerable skill, therefore, to recognize Armillaria mycelium with absolute certainty.

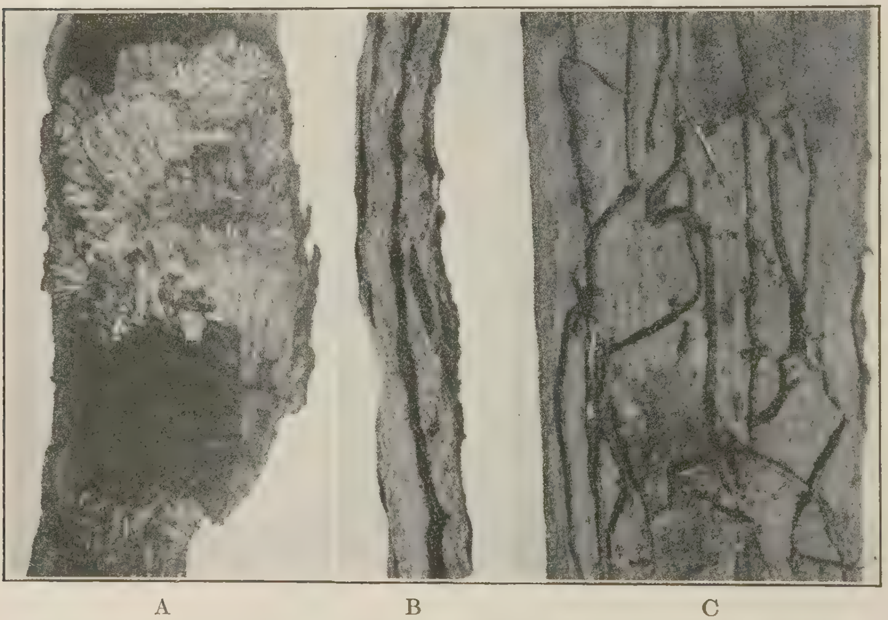

FIG. 5.—*Armillaria mellea.* A, Fan-shaped mycelium on inner side of bark of orange root; B, rhizomorphs on surface of orange root; C, rhizomorphs on surface of a stake that had been driven into ground. (B and C *after Darnell-Smith* (1914).)

The white mycelium of Armillaria penetrates also into the wood as well as into the bark. It produces a white soft rotting of the wood, from which a watery liquid may be squeezed out. From a wet, soggy condition, the dead wood may finally go down into a jelly-like mass of material with the dead bark still more or less intact but lined inside with white fan-shaped felty layers of mycelium, and usually marked outside with the black rhizomorphs. Wood that is decaying rapidly from the

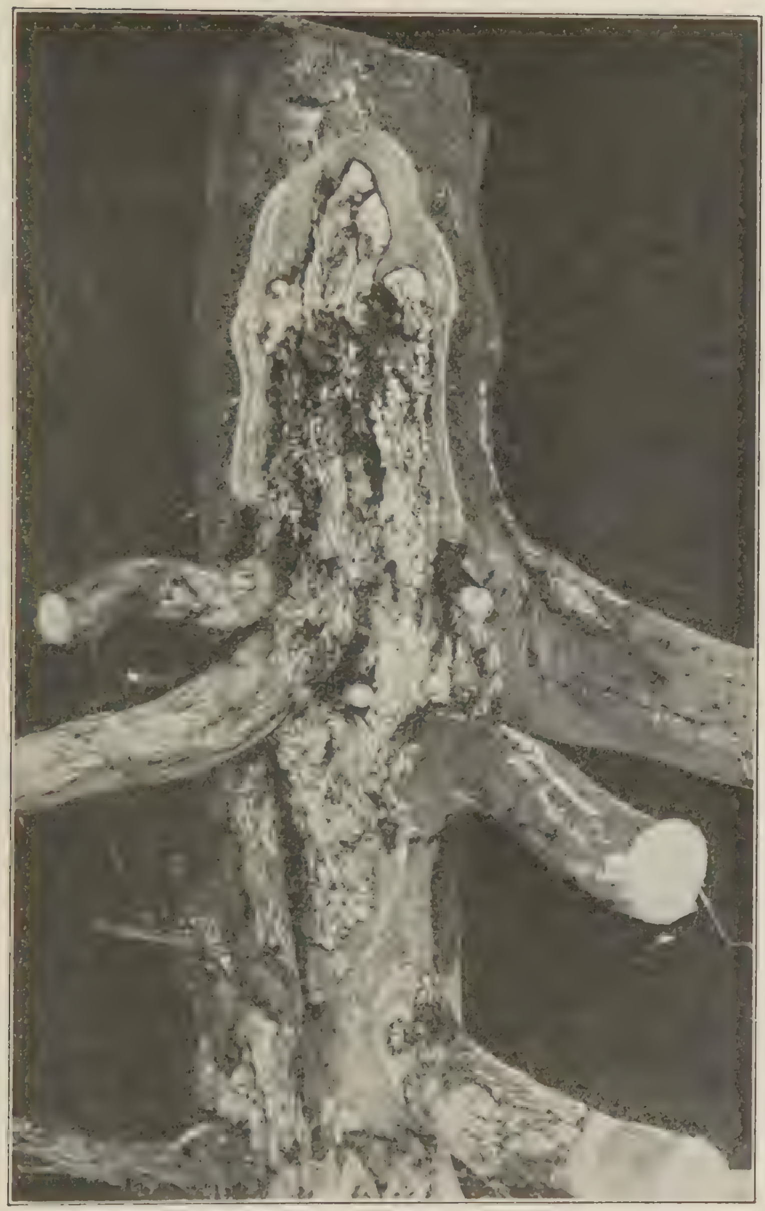

Fig. 6.—Trunk and base of main roots of lemon tree containing white mycelial fans of *Armillaria mellea.* (*After Barrett* (1918).)

invasion of Armillaria frequently shows a phosphorescence when exposed in the dark.

Contributing Conditions.—The Armillaria root rot is usually found in situations where native trees have been growing previous to the planting of the orchard. In California, land on which oaks or sycamores originally grew is often subject to the Armillaria root rot. After the trees are taken out, the fungus, if present, grows and lives as a saprophyte on the pieces of roots or wood fragments of considerable size left in the soil and from these attacks the Citrus roots. Hendrickson (1925) finds that while the oak trees are living, the fungus cannot penetrate the cambium layer, but after their death it spreads through the dead or dying roots. In some cases cultivated trees on the roadside or in private yards may first be killed and the fungus may travel from such roots to an adjoining orchard of Citrus. Pepper trees (*Schinus molle*) appear to be especially susceptible in southern California. The fungus is favored by old stakes

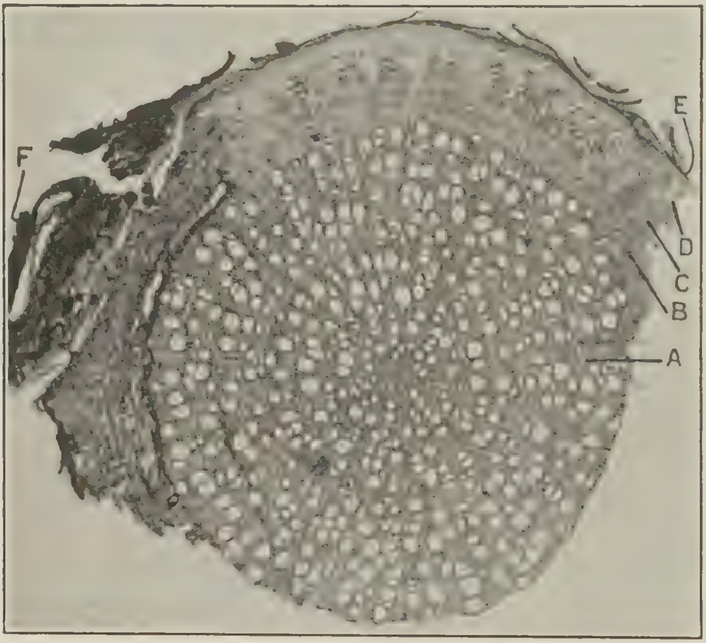

Fig. 7.—Cross section of a small Citrus root showing a partially imbedded rhizomorph (F) cut across on the left and the bark underneath disintegrating. Bark at the top is normal. In the center is the wood (A) indicated by the presence of the large openings; this is surrounded by a narrow cambium layer (B) between the wood and the bark. Outside of the cambium is the phloem (C) made up of the sieve tubes, seen here in cross section, with extensions of the medullary rays running into it. Outside of the phloem, are the thin-walled loose cells of the cortex (D) and finally the epidermis (E) covering all, on the exterior. Much the same arrangement is found in stems; compare Figs. 93 and 150. Magnified about 15 diameters. (*Photo contributed by J. T. Barrett.*)

left in the ground (Darnell-Smith 1914) and in Tasmania it has been observed by Nicholls spreading from underground wooden drains.

Armillaria root rot is, of course, favored by damp, wet conditions but also spreads well even under the usual irrigation practices that are most favorable for tree growth. The fungus cannot spread rapidly under dry conditions. The exposure to the drying effect of the air of an actively spreading diseased lesion at the base of a Citrus tree usually results in halting the advance of the fungus. Under California conditions the mycelium of the fungus is seldom found extending very far above the surface of the soil.

Control.—The control methods for Armillaria root rot vary considerably according to circumstances. Prevention and treatment for this disease are best discussed together.

Clearing Land before Planting.—If land on which oaks or other trees likely to be infected with *Armillaria mellea* is to be cleared for planting, care should be taken to get out as many of the larger-sized roots as possible and pile them up to dry or destroy them. If any roots are visibly affected they should be burned. The same would apply to clearing off an old apricot, peach or other infected orchard, with the idea of planting to Citrus. In plowing, avoid dragging roots from infected to non-infected portions of the land. In areas known to be infected the infected portions of the land should be plowed separately from the non-infected for safety. If time is not a factor, the land may be sown for a year or more to an annual crop which, when being plowed under, brings to the surface more of the roots that may later give trouble. On planting the orchard, one should be sure that the trees have been grown in soil free from Armillaria root rot. If the land to be planted has been in fruit trees before, avoid, if possible, planting the individual trees in the same holes occupied by the former trees.

Treatment and Prevention of Spread in the Orchard.—The control of Armillaria root rot when found in an orchard presents two problems: (1) the prevention of its spread to healthy trees, and (2) the handling of the trees already diseased. As far as known, the disease, after it is once established, progresses in an orchard almost entirely below ground, communicating from a diseased tree along its roots to the roots of a healthy tree, spreading, in turn, along the roots of this latter tree to the trees surrounding it, etc. The rate of spread is variable, but seldom, even under the most favorable conditions for the fungus, does it travel faster than to kill out more than one Citrus tree in a given direction every two years. Frequently, Citrus trees are very resistant and the spread is very slow. It is important, as soon as discovered, to ascertain first how many trees are affected even slightly. The roots may be considerably diseased before any evidence shows in the tops. The disease is usually present in a definite localized area or in several areas; it may, however, be scattered. Great care should be exercised in examining all the trees surrounding a diseased tree or group of trees, for the traces of Armillaria root rot. Examination should be made by digging down around the crown and out along some of the main roots, especially in the direction of a tree known to be diseased.

Having located the diseased trees, the next procedure is to prevent the fungus from extending any further through the soil. Several barrier methods have been employed, such as trenching, the use of carbon bisulfide, etc. For localized areas, trenching, with or without permanent barriers, is probably the best. It consists in separating the diseased area of trees from the healthy with a trench of sufficient depth to extend below all the communicating roots. By cutting and examining all the roots crossing this trench, it may be found that the disease has already passed outside of the supposed area of the disease. The trench must then be changed in order to include the next tree.

After the diseased area is definitely isolated by the trench, it may be filled up again when necessary and the diseased area given attention. If the affected area contains mainly sick or dying trees, the following procedure may be carried out. Dig out the trees either before or after carbon bisulfide treatment as outlined below. Use care to remove, as far as possible, all large roots. The roots should be destroyed by burning, preferably on the area itself, to avoid scattering the diseased fragments. Treat the entire area inside the trench with carbon bisulfide in the following manner: Bore holes, with a soil auger,[1] 1½ to 2 feet apart in every direction and 1½ feet deep. Pour into each hole 1½ ounces of carbon bisulfide and plug it up quickly with earth. The soil should be fairly dry, but not too dry. In dry, loose soil, a surface layer of 2 or 3 inches may be wet down before boring the holes to keep the gas from escaping too rapidly. Fumigation tent canvas spread over the soil would also serve the purpose even better. The carbon bisulfide tends to kill out all the Armillaria, as well as other vegetation, in the soil. In some cases where the trees are to be sacrificed anyway, it may be better to treat the area with carbon bisulfide before digging out the trees as in the next method suggested. This has the advantage of killing the fungus on the roots before they are taken out of the ground.

Sometimes it seems advisable not to sacrifice the diseased area at once, but to treat the trees and prolong their usefulness for a number of years. In such cases either permanent barriers between the infected and non-infected portions may be used, or the trench may be redug at least once every two years to cut away and examine all communicating roots. In certain cases, cement barriers with the top just below the surface have been constructed. For large areas cement is expensive, and if the area is not correctly determined at the original investigation, infected trees may

[1] In some soils holes may be made more rapidly by means of iron bars or "gopher probes."

later be found outside of it. A trench which can be reopened once every two years and then filled up again is probably the most practical method of isolation. The location of the trench may be changed more easily than a barrier of cement or other material. Another method of isolation which has been used is to put carbon bisulfide in a double row of holes 1½ feet apart halfway between the trees as a substitute for the trench. This, however, does not give the same opportunity of examining the communicating roots that the trench affords.

If the diseased trees are scattered, a method used with success by C. L. Sheldon of Santa Paula, Cal., for the past ten years may be suggested. As soon as an isolated diseased tree is discovered, a square or rectangular area with the tree in its center and its boundary one-half way or more toward the adjacent trees is treated with the carbon bisulfide while the tree is still standing. Larger amounts of the liquid and a few extra holes are bored near the crown of the tree. This treatment, of course, kills the tree, which is allowed to remain standing for some weeks, after which all the mycelium of the fungus is found to be blackened and dead. It is possible that some secondary decomposing reactions help to kill out the organism completely after such treatment. The tree and its roots are then dug out, a large hole left for some time, when possible, and a new Citrus tree planted. In ten years of such procedure on a silty loam soil in which a considerable number of trees have been replanted, no replants have become affected. For safety it is well in any case to wait several weeks after using the carbon bisulfide before replanting.

Saving Diseased Trees.—In certain cases where trees are not too severely affected when found, it may be advisable to attempt to save them or to prolong their lives. If only a few roots are attacked, these may be carefully removed and all dead portions of the bark and wood cut away and the wounds carefully disinfected and painted. As stated previously, the fungus is sensitive to drying out. Digging away the soil from a portion of the roots or trunk affected and leaving the place open as long as possible after treatment is beneficial in stopping the advance of the fungus on the roots or crown.

After the fungus is killed out by removal of several large roots or a portion of the bark at the crown, it may be feasible with a large tree to inarch in order to rejuvenate the side of the tree affected. In Tasmania, a method of laying bare the roots 2 to 3 feet from the trunk, scraping away the rhizomorphs and mycelium and soaking the roots with potassium permanganate 1 ounce to 4 gallons, or scattering crystals of iron sulfate over them, has been reported by Nicholls as successful. According to Hendrickson, experiments with this method in California have so far given no beneficial results.

Planting Resistant Varieties.—Sometimes it is desired to replant with resistant trees. In California, the northern black walnut (*Juglans* *californica* var. *hindsii*), fig (*Ficus carica*) and French pear (*Pyrus communis*) are all fairly resistant stocks. Most avocados are thought to be more resistant than Citrus.

ROSELLINIA ROOT DISEASES

The Rosellinia root diseases, also called "black root," occur in the tropics, especially on forest lands recently cleared and on trees growing in proximity to dead and dying stumps. In plantations of lime trees (*Citrus aurantifolia*) in the West Indies, two very similar Rosellinia root diseases due to two closely related fungi, *Rosellinia pepo* Pat. and *R. bunodes* (B. *et* Br) Sacc., have given trouble. Sweet orange (*C. sinensis*) and sour orange trees (*C. aurantium*) have also been noted as liable to attack.

History and Distribution.—Rosellinia root rot is reported by Nowell (1917*a*) as occurring in Guadeloupe, Dominica, Martinique, St. Lucia, St. Vincent and Grenada, but as unknown in the remaining islands of the Lesser Antilles that have drier climates. The range of hosts attacked by this disease is an exceedingly varied one, including practically all the important cultivated plants in the West Indies. The cultivated host most affected is cacao. A similar disease has been reported on Citrus; on oranges in Yucatan by Gandara (1910), on oranges and citrons in Argentina by Hauman-Merk (1915) and on oranges in Brazil by Averna-Sacca (1917).

A Rosellinia root-disease fungus of the vine in Europe was known in early pathological literature under the name of *Dematophora necatrix*, which referred to the imperfect or conidial fructification, the only form of the fungus known at that time. The perithecial form was later discovered and described by Viala.

Symptoms.—The disease, according to Nowell (1919), manifests itself in the aboveground portion of the lime trees in three ways: (1) by a gradual defoliation preceded by yellowing of leaves and a general sickly appearance; (2) by the setting of an abnormally large crop of fruit, which often shrivels and becomes prematurely yellow; and (3) the appearance of bare branches resulting from a sudden shedding of all the foliage. The first manifestation usually indicates that the roots have become more or less affected before the fungus has gotten up around the crown of the roots or "collar" of the tree, while the second and third indicate that the stem has been girdled while most of the root system remains unaffected. In some cases the top shows no definite sign of the disease until it suddenly wilts. In extremely severe examples, the tree will be dead in two or three days after wilting begins. In these different effects on the aboveground portion of the tree, the disease acts much as does Armillaria root rot on Citrus.

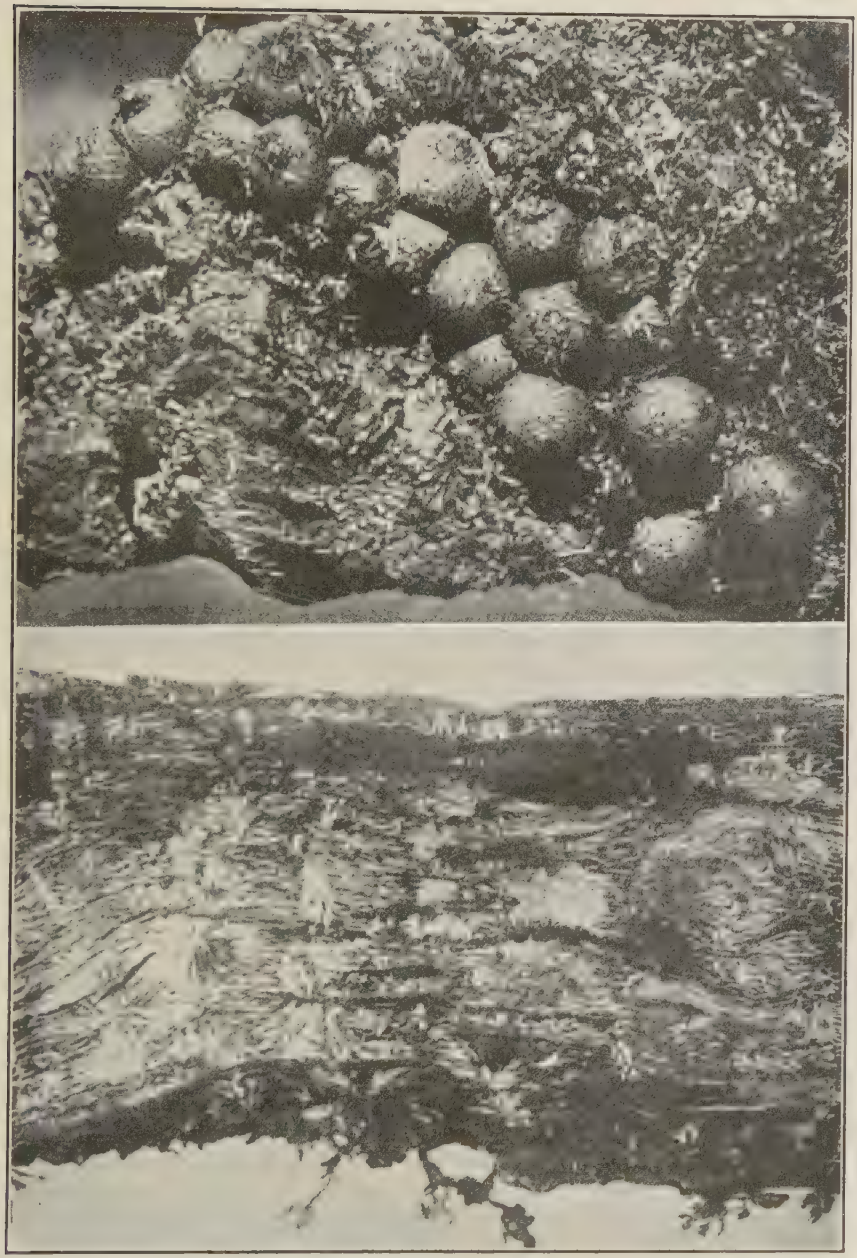

FIG. 8.—The Rosellinia root disease fungus, *Rosellinia pepo:* (*Upper*), showing the spherical fruiting bodies (perithecia) which bear the asci and spores shown in Fig. 9, ×3½; (*Lower*), white mycelial fans or stars as they appear under the diseased bark, natural size. (*After Nowell* (1917).)

A tree recently killed by this disease will usually show most of the lateral roots dead and their surfaces covered with fungus mats or mycelium, dark brown and intermixed with earth. On the surface of larger roots is seen brown mycelium, while underneath the bark on the wood are white fan-shaped mycelial masses, turning yellow when old. These fans are not so common on lime as on cacao roots. On the upper portion of the old roots and at the base of the trunk, a thin crust of black, carbonaceous stroma is seen just below the surface of the bark.

On the surface of the bark of trees nearly dead, extending 1 foot or more above the soil, there is often a continuous weft of dark olive-green mycelium covering the entire surface. It shows a light-gray margin along its advancing edge.

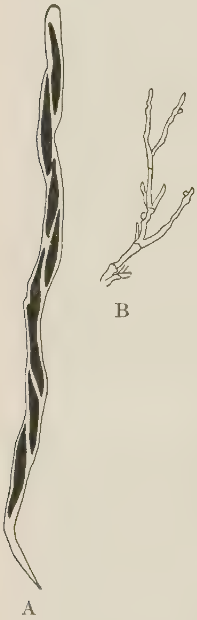

Fig. 9.—One of the Rosellinia root disease fungi *Rosellinia pepo;* A, spore-bearing sack (ascus) of the fungus containing eight elongated spores, ×175; B, terminal hypha of conidial fructification or Graphium stage of same fungus. (*After Nowell* (1917).)

The Fungi.—*Rosellinia pepo* Pat. and *R. bunodes* (B. *et* Br.) Sacc. are the two species found on limes. *R. pepo* is distinguished from the other species (Nowell 1917) by "fans or stars of white mycelium in the region of the cambium, between the bark and wood, on the roots." On the surface of the roots is formed an irregular coating of mycelium, smoky gray at first, becoming black. In the outer bark are formed dense layers and pockets from which whitish strands penetrate the cortex. When these whitish strands reach the surface of the wood, they form a white pattern of branching lines, fans and stars which is repeated on the inner surface of the bark (Fig. 8). Strands also penetrate the wood in radial lines along the medullary rays.

The description of the fructification of this fungus by Patouillard is as follows:

> Perithecia (Fig. 8), scattered or in groups, situated on the crustaceous, conidia-bearing subicle, globose, somewhat stalked, 2.5 to 3 millimeters in diameter, dark brown, carbonaceous, furnished with a conical shiny black osteole remaining closed, surrounded by a darker somewhat more flattened areole; asci (Fig. 9) elongate, capitate at the apex, furnished with an ovoid pore, turning blue with iodine, much attenuated below, eight-spored, 10 to 12μ in breadth, paraphyses numerous, linear; spores brown, straight, fusiform pointed at each end, measuring 62 to 67 by 8 to 9μ, at first increased at each end by a glassy halo, later bare. There are present erect conidiophores 1 to 3 millimeters in length, 30 to 60μ broad, composed of brown septate hyphæ 4 to 6μ thick, situated on the crustaceous subicle. Conidia not seen. The conidial fructifications (Fig. 9) are much more often seen than the perithecia. The conidia occur previous to the

development of perethecia on the black surface mycelium that develop as the fungus reaches the open under damp conditions. The conidia are borne on a black stalk 2 to 3 millimeters long formed of a union of parallel hyphæ which branch at the top into a tuft. This tuft appears white when covered with the conidia which are borne laterally near the ends of the branches. Conidia are ovoid one-celled and about 5μ in length.

Rosellinia bunodes in its general course of development and main characters is similar to *R. pepo.* Its characteristics on the roots are given by Nowell as follows:

> At the point of infection on a lime root, the bark takes on a greenish tint and a dead patch extending to the cambium is formed in it. From this, the fungus spreads over the bark and through the cortex, the infestation of the wood following later. The mycelium on the surface consists mostly of closely applied, firm-textured, branching, black strands which thicken into irregular knots along their course.
>
> At a later stage the space between the strands may fill in so that a dense layer is formed, which on its lower surface grows between and encloses the outer layers of the bark, and on its upper surface bears in relief a closely ramified system of rhizomorphic strands. From the lower surface abundant cylindrical strands, with a black periphery and a white core, penetrate the cortex in a direction more or less vertical to the plane of the cambium. On reaching the wood they run for a short distance over its surface, and distribute themselves into it by branches which penetrate by way of the medullary rays. The result of this distribution is that the strands are seen in the wood of a transversely cut root as black dots and radial lines; in a median, longitudinal section as vertical and horizontal lines; in the bark as black threads of irregular length and course.
>
> As in the case of *R. pepo* the surface mycelium ascends the stem for some distance aboveground as an encircling sheet. In this species the whole sheet when quite fresh may be creamy white in color; it eventually turns black. The bark beneath commonly remains healthy for some time after it has become covered, but it is eventually penetrated and killed. By the further development of the mycelium a sort of crust is formed on which the conidial fructifications and perithecia successively arise.
>
> Perithecia densely crowded, embedded at first in a purple-brown mycelium, superficial, brownish-black, globose, up to 1.6 millimeter diameter, carbonaceous, verrucose with close-set, somewhat pyramidal warts arranged more or less concentrically, ostiolum sometimes papillate, sometimes not elevated, wall of perithecium thin, brittle, about 0.1 millimeter thick, black internally, asci 285 to 357μ in length, spores variable in size 80 to 110 by 7 to 12μ exuded in narrow threads without much adhesion, cymbiform or sometimes lanceolate; ends acute and produced into a thread-like point which in longer spores may reach a length of 25μ, brownish black, opaque. Conidia like those of *R. Pepo.*

Contributing Conditions.—The diseases due to Rosellinia occur, in the West Indies, near decaying stumps and on logs on forest land recently cleared. High humidity and shade are also usually important factors in the prevalence of the diseases. Some of the forest trees from the dead stumps of which the fungi most commonly spread to infect the roots of lime are *Sterculia caribaea*, *Sloanea massoni*, *Daphnopsis tinifolia*, *Algiphila martinicensis*. The Rosellinia diseases have not been reported in lime plantations that have had no recent clearings.

Control Measures. *Prevention.*—If it were economically possible, the ideal prevention, as pointed out by Nowell (1917), would consist in removing all stumps and logs from newly cleared land destined for the planting of limes. Although this is not feasible under West Indian conditions, Nowell mentions certain precautions which may be taken when new orchards are planted, so that the damage from the disease may be greatly reduced when it appears. The trees may be planted in blocks separated and isolated one from the other by means of trench drains, and, where possible, each row separated from the next by a trench. In planting the trees, care should be taken to avoid close proximity to stumps or rotting logs. Where possible, a trench should be dug 2 or more feet wide, well away from the susceptible stump, and all sections of roots should be removed. The fungi thrive especially in continuously damp situations and cannot persist under dry conditions. It is, therefore, desirable to encourage free circulation of air under the trees by clearing away weeds and excess of soil about the base of the trees and by cutting off low-hanging branches. In plantings especially susceptible, the base of the trunk and the main roots should be completely bared of soil. As an added protection, lime sulfur or other fungicide may be applied to the bark of the trunk and main roots.

Treatment.—The treatment of the diseases as worked out in the West Indies and described by Nowell (1917) is mainly as follows: In diseased orchards where surface infection is taking place, a careful inspection at the base of the tree trunks will lead to the detection of many light cases which may be successfully treated, thus saving many new centers of distribution. The lower branches should be pruned to allow access to the trunk, weeds and earth should be cleared away around the junction of roots and stems, preferably using the hands or a blunt instrument to avoid injuries to the bark. A careful investigation of each tree should be made in this way at least twice a year.

The principles of the actual treatment are according to Nowell:

> (*a*) complete excision of diseased tissues; (*b*) exposure as complete as possible of the affected part and its surroundings to freely circulating air, with the object of making the conditions too dry for the fungus to exist. In operating it must be remembered that after the early stages the fungus penetrates wood as well as bark. It is the drastic surgery made necessary by this fact, and the propensity of the fungus for lateral spread in the outer zone of roots, that make the saving of cases at all advanced so hopeless.

The treatment of trees with deep-seated development of the disease involves so much skilful surgery that it is usually not economically profitable to spend time and money in attempting to save them. When such trees are to be destroyed it is best to choose a dry day. Spore-bearing surfaces should be flamed with a torch or by burning trash over them (Petch 1910), in order to keep down the aerial dispersal of live spores. The stump and roots of the diseased tree should be removed as completely as possible and burned.

Where the disease has already killed out a patch of trees and is being communicated along the roots from diseased to healthy trees, trenches should be dug so as to separate the roots of the diseased trees from contact with the healthy ones. The principles of procedure are similar to those described for Armillaria root rot; namely, to ascertain carefully as far as possible all trees already affected even in the beginning stages and to separate these by means of trenches from those that are not yet affected; then to cut away all roots in this trench, thus preventing communication of the disease from tree to tree by contact of roots. Nowell suggests that the trenches should be cut outside of all the trees in contact with diseased trees, as it is difficult to tell on which of the contact-tree roots the disease has already progressed. A checkerboard system of trenches, isolating each tree from its neighbor in addition to the main isolation trench about the whole suspected area, is also of value in protecting individual trees within the suspected area onto which the fungus has not yet spread. Such cross trenches will also serve to reveal contact roots partly or slightly diseased which may be removed in time to save the tree.

The control measures, briefly summarized, consist in: (1) prevention by exposing soil and bases of trees, logs and other dead material to the wind and sun and by a close system of trenches to prevent root contact where necessary; (2) treatment by cutting away diseased portions in the early stages and by periodic tree-to-tree inspection, by flaming and promptly digging out and burning badly infected trees, liming and exposing the soil and by isolating all adjacent trees by trenches.

SCLEROTINIA ROOT ROT

Under certain conditions favorable to the fungus *Sclerotinia libertiana*, and unfavorable to the Citrus tree, much injury to roots may be brought about. This injury has been observed usually in lemon trees and on heavier types of poorly drained soil that have a tendency to get too wet by overirrigation or excessive rainfall. The same fungus is found in connection with gummosis (p. 153), twig blight (p. 310) and rot (p. 380).

Symptoms.—The fungus may either get into wounds near the trunk on some of the main roots and rapidly produce large lesions sometimes extending up onto the trunk as in Sclerotinia gummosis, or it may start at the extremities of the roots and work back toward the crown. The

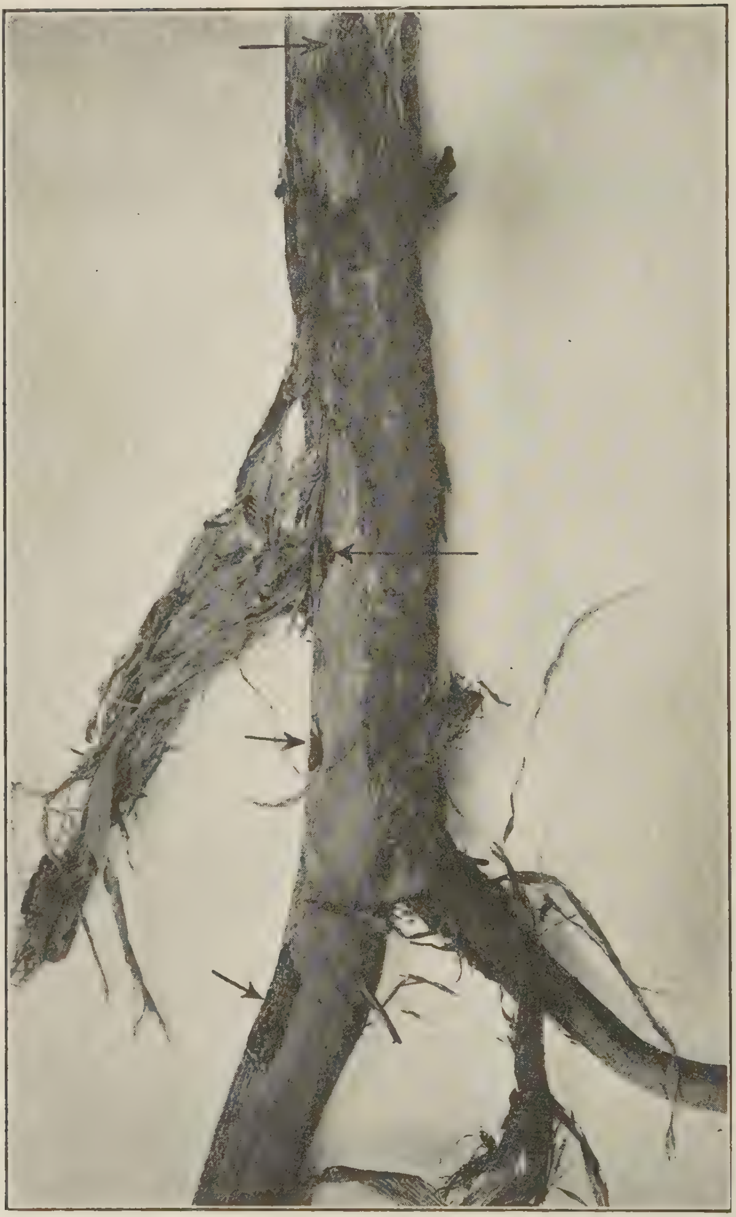

FIG. 10.—Sclerotinia root rot, showing shredded condition of cortex and black sclerotial bodies indicated by arrows. About natural size.

condition of the tree and soil will determine how fast or how far it may be able to progress. In most cases the death of the roots does not extend to the crown, but a resistance is set up which cuts off its further progress. It seems probable that the roots are usually weakened by some unfavorable condition before they are susceptible to attack. Coit, who has made many observations on this form of root disease on lemons in California, states that the general symptoms are a cessation of suckers or new growth in the tops, a reduction of the amount of fruit and a general sickly appearance. Its degree depends on the number of roots affected. Occasionally, the fungus follows a root to the crown and then girdles the tree, causing it to die suddenly. The bark of the roots presents a shredded appearance when pulled from the woody cylinder (Fig. 10). There may also be present cottony white mycelium and black sclerotia within or under the bark. These last characteristics, however, may be absent.

Control.—Preventive measures consist in avoiding the contributing conditions of lack of drainage or too much water on the heavier types of soil. Also the avoidance of unnecessary injury to the roots under the same conditions.

Treatment of trees partially affected consists in cutting the trees back in proportion to their degree of apparent injury. The limbs should not be stubbed back but cut back to another limb. The tree should be thinned out or skeletonized rather than headed back. Coit suggests reducing the size of the tree without changing the general shape or destroying the main framework. Late spring or early summer in California for lemon trees, after the main crop is picked, is a good season. The trees should be sprayed or painted with whitewash immediately after thinning the branches in order to prevent sunburning.

DRY ROOT ROT

A disease of the roots known as dry root rot is of considerable importance in California. Root diseases of the same general nature have been described as occurring in other countries. This root rot has been designated by the term "dry" to distinguish it from the wet or disintegrating types of root rot like that of Armillaria and certain phases of mal di gomma, Pythiacystis gummosis, etc. It is only in its later stages, however, that it is really a dry root rot.

Symptoms.—Decay of the bark and wood takes place on roots at and below the crown and usually below the surface of the soil. In the active stages of the decay, especially when it is starting, the bark is moist, and if the soil is wet, there may be a semimushy condition. This is not so pronounced or soft as in certain other root rots. Usually no gum is apparent, but occasionally a small amount is visible at the advancing edge of the active lesions. The disease is often associated with mal di gomma or with Pythiacystis gummosis, in which case considerable gum may be present. Large or small lesions may occur on roots a little distance from the crown, or the entire crown and base of main roots may be involved in varying degrees (Fig. 12). It may start on the side of a tap root or on large lateral roots and later spread to the crown. The bark is at first soft, soggy and darker than normal. When further decay sets in, it becomes drier and crumbles away. Hard dead wood is found underneath. There is a tendency for the lesions to enlarge for a time and then become self-limited by production of callus. Smaller lesions may be partially covered with new bark as time goes on. Unlike pure Pythiacystis gummosis or mal di gomma, the wood usually becomes affected for some distance inward. The wood becomes light brown, and remains firm as the dry root rot proceeds. This dry decay in the wood frequently involves a greater part of the woody cylinder of the root and consequently has a severe effect upon the tree.

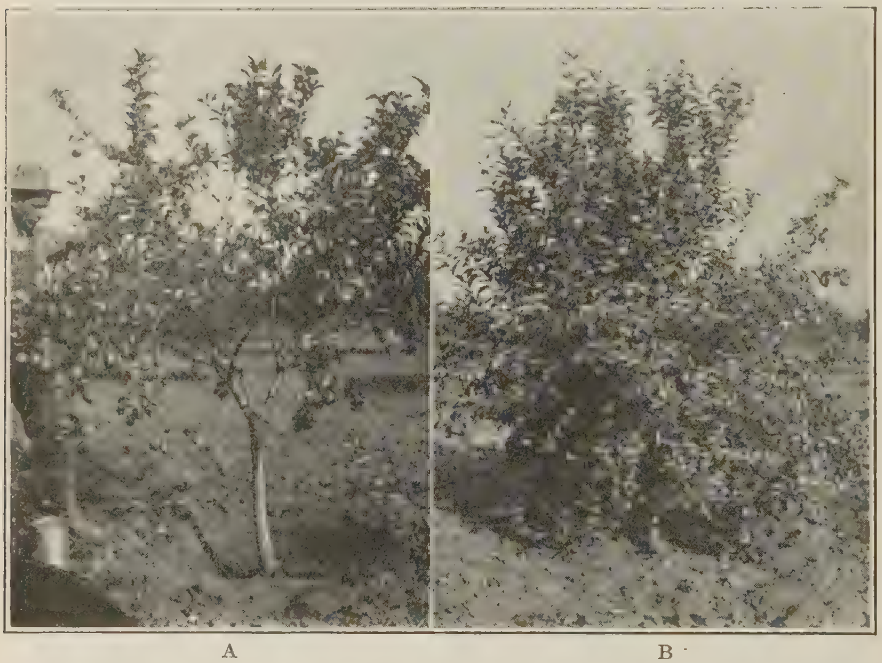

Fig. 11.—A, young lemon tree affected with dry root rot; lateral branches are few, the foliage sparse and pale and crop too large for the age of the tree; B, typical lemon tree of same variety and age not affected, and with full healthy growth.

The symptoms above the ground are usually manifested by an open, thin appearance of the tree, yellowing and dropping of foliage and frequently the setting of an unusually large crop of fruit (Fig. 11). The effects are much the same as if the trees were gophered or had severe mal di gomma or Pythiacystis gummosis. The leaves may wilt suddenly,

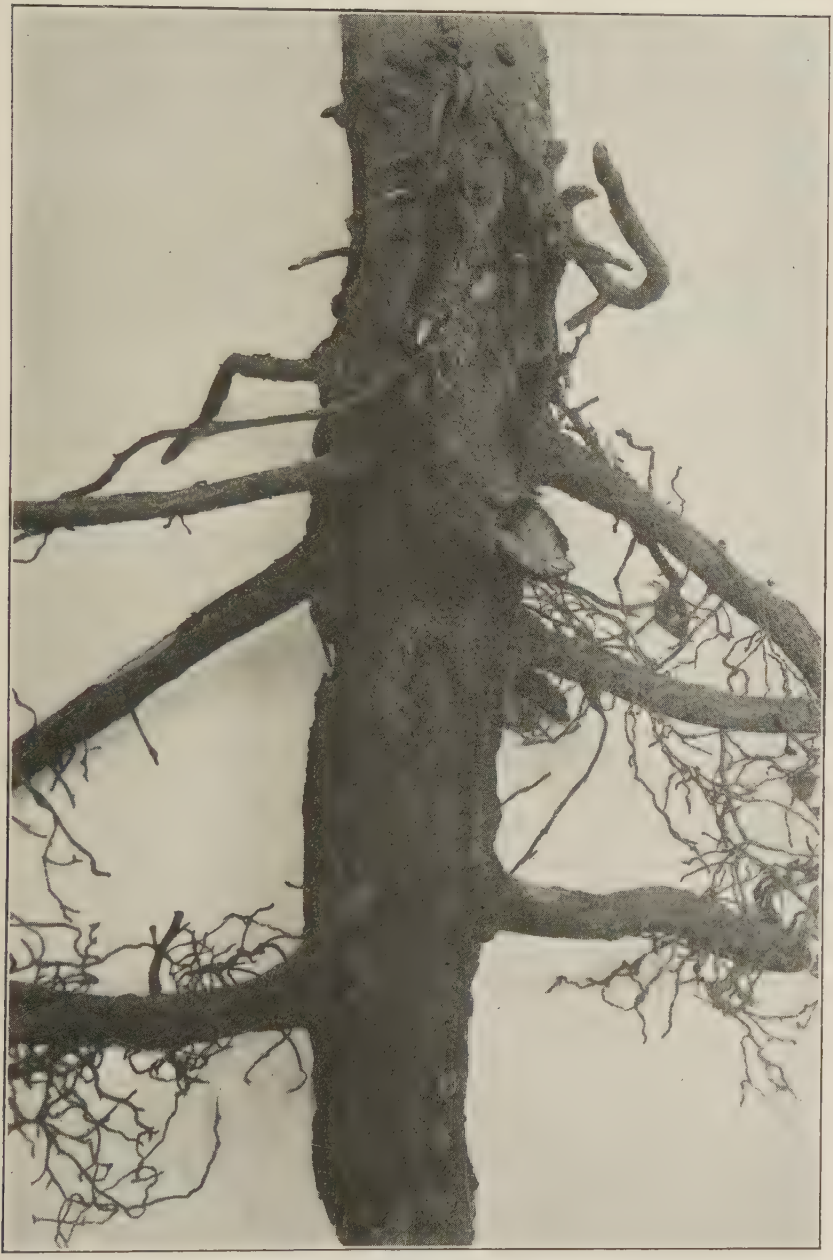

FIG. 12.—Dry root rot lesions on young orange tree root.

and the entire foliage and twigs dry up in a few days, or the tree may have a lingering, more gradual death, in which it first becomes slowly defoliated. Sour orange (*C. aurantium*) as well as sweet orange (*C. sinensis*) may be affected.

Contributing Conditions and Probable Cause.—The investigations of Barrett in California (1920) have shown that fungus species of Fusarium are nearly constantly associated with dry root rot lesions. He states:

> The fact that different species of Fusarium have been isolated from different cases of the disease occurring in different sections would indicate that closely related types of dry root rot may be induced by several species of the genus Fusarium.

The writer has also found Fusaria commonly in the dry root rot lesions. Inoculation from pure cultures of Fusaria as well as from diseased tissue has so far failed to reproduce the disease in its severe form. Only small lesions have resulted. This was also the experience of Earle and Rogers (1915) in Cuba. A number of other authors have reported species of Fusarium as having probable relation to types of root rot and gummosis: McAlpine (1899) in Australia, Briosi (1878) in Italy and Jaczewski (1917) in southern Russia. Although the characteristic later stages of the disease have not been reproduced by inoculation with Fusarium, it is still thought to be at least a factor when acting under the right set of contributing conditions.

Some of the conditions thought to be important are excessive moisture, poor aeration, heavy soils and possible injuries to the roots, such as larvæ of Fuller's rose beetle, rodents, heavy fumigation with cyanide, etc. Excessive moisture at the base of the tree is probably one of the most important conditions. The lack of aeration would naturally accompany or follow excessive moisture. Heavy soil, while possibly a factor, is not necessary to its occurrence. Some very severe cases have been found in a sandy type of soil. Savastano (1922*a*) refers to a root rot of rour orange in Sicily known as "cagna," in which some of the aggravating factors are thought to be defective aeration in compact water-logged soil, forced cultivation, close planting, excessive manuring at long intervals and improper irrigation. A root rot reported by Spegazzini (1920), which is thought to be a non-parasitic trouble due to unsuitable soil conditions, is especially severe on mandarin oranges in South America.

Control.—No thoroughly satisfactory method of control appears feasible for advanced stages of the dry root rot, since the wood as well as the bark is affected. The method of cutting away only the diseased bark, as in pure mal di gomma and Pythiacystis gummosis, is not sufficient. If only certain roots are affected and the tap root and crown are still in good condition, these diseased roots may be cut out and destroyed.

A lesion not too far advanced at the crown of a large tree may be carefully cut away, care being taken to cut some distance beyond the visible margin of the dry decay in the wood as well as in the bark. The wound may be disinfected with mercuric cyanide or mercuric chloride (1 to 500), Arrow carbolineum or some other fungicide and covered with thick asphalt paint or tar. Wounds made in cutting off large roots may be covered in the same way.

Prevention consists in avoiding excessive water especially near the crown, providing good aeration and drainage and avoiding injuries to the roots. These same precautions will also help in preventing Pythiacystis gummosis, mal di gomma and other troubles that depend to a considerable extent on the same contributing conditions. Under some conditions of very heavy soil, a preventive Bordeaux wash may also be applied to the base of the large roots and crown.

PORIA FUNGUS ON ROOTS

A white fungus, *Poria vaporiora,*[1] which might be mistaken on superficial examination for the cottony rot fungus, *Sclerotinia libertiana,* has been observed abundantly on the roots of Citrus trees growing in the so-called "dry bog" soils of Tulare County, California. It is found in situations where the soil tends to be water-logged at times, and is believed to be secondary, merely breaking down and rotting the bark and wood of the roots after they have been killed by water logging or injured by other organisms.

Appearance.—A white, smooth, felt-like coating forms over the surface of dead parts of roots and also sometimes extends upon the surface of the live parts without penetrating the bark. It may also form on the surface of stones or sticks in the soil. Portions of the root that have been dead for some time are more or less pithy, but not soft or punky, showing a dry white rot.

On the surface of some of the white felt-like layers is formed the fruiting stage of the fungus consisting of a fungal tissue of parallel tubes about ⅕ inch (4 to 5 millimeters) long at right angles to the root. This fruiting portion is white to sea-foam yellow in color. Associated with the Poria were found *Trichoderma lignorum* and *Fusarium sp.*

Another species of Poria, *P. cocus,* is mentioned by Weber (1924) as occurring on a tuckahoe found attached to an orange-tree root in Florida.

WATER INJURY

Many observations have been recorded of the serious effects on Citrus roots of lack of drainage, high water table and the like. In addition to encouraging various forms of root and trunk diseases, already mentioned, too much water prevents proper aeration and often injures the physical and biological conditions of the soil. A water table too near the surface is very detrimental to Citrus trees. A high water table may be permanently high in some cases but usually fluctuates, being higher at certain seasons than at others. Some species or varieties of Citrus rootstocks, such as sour orange, are apparently capable of resisting temporary high water better than others, but all Citrus roots will be injured by long exposure to a high water table or to excessive water.

---

[1] We are indebted to Dr. E. A. Burt for identification of this fungus.

Symptoms.—The fibrous roots are sloughed off and even the larger roots die or are weakened by development of dead areas. The larger roots may eventually die and become black or are invaded by wood-rotting saprophytic or semiparasitic fungi. Soft wood decay may follow in severe cases (Fig. 13). This sloughing off of the fibrous roots has an effect upon the top, usually manifesting itself in reduced growth, small yellowish leaves and dead twigs.

Floyd (1915), as a result of experiments with Citrus trees grown in tanks of sandy loam soil, in which a known height of water table was maintained, reports the symptoms of injury produced in young trees. The soil was about 30 inches deep. Three sets of ten orange trees each on sweet-orange roots had the following treatment: First set, with water table 7 inches from the surface, the second, with water 14 inches from the surface and the third in good moisture without saturation of the soil.

In about four months, from October to February, and after the second flush of growth, the leaves of the first set showed a slight yellow tint with ranker growth, the second a normal green and the third a shade lighter. In one year from planting, the first with highest water table had very sparse yellow foliage, smaller leaves than the others, shorter stems and "hide-bound" bark. The trees looked open and sickly. The second with the water table 14 inches from the surface had a luxuriant growth and a normally colored foliage, but long angular stems and larger leaves than the third set. The third set without any water table but with moist soil had a good growth with shorter, more plentiful, less angular stems but leaves lighter green than the second set. It was found that the soil had become dry at the bottom toward the end of the experiment. When the trees were removed at the end of 18 months, the roots in the first set with 7 inches to the water level had stopped growing below the water surface and were sloughing off where they had dipped into the water. The second with 14 inches to water level had roots completely filling the soil down to the water table, also with sloughing of roots when dipping into the water. In the third without water table the mat of roots extended entirely to the bottom of the tank. The roots were of good color with plenty of fibrous laterals.

These results as to type of growth appear to agree well, according to Floyd, with observations in orchards under Florida conditions. Where trees are planted in lands where the water table is near the surface, an open type with sparse, small, yellowish foliage is obtained. In moist hammock soils where the water table is lower and there is room for root development along with constant supply of moisture, the type is like the second set in the above experiments; long, succulent, more or less angular shoots, with larger green leaves. In drier well-aerated soils, having fair moisture most of the time but occasionally dry, trees grow less open and more bushy with shorter more plentiful shoots. When moisture is irregular and not sufficient at times, as was found in the bottom of the tank of the third set, the leaves become somewhat smaller, and a shade lighter, but the trees still remain in a fairly healthy condition.

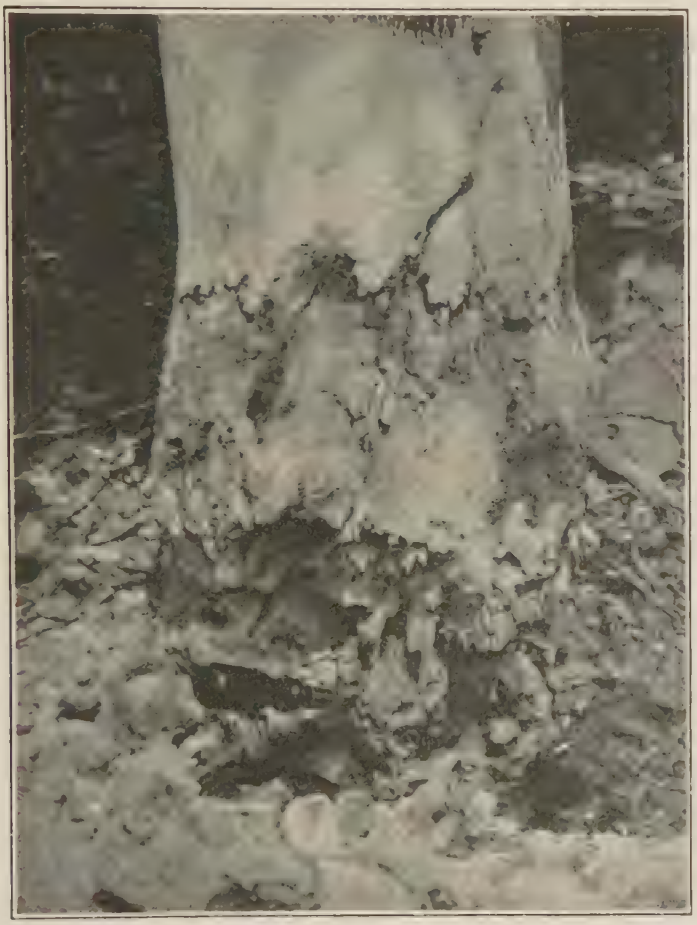

Fig. 13.—Tree trunk in which the soft punky rotting of the base, resulting from too much water at the roots, has extended upward on the trunk. (*Photo contributed by W. Schoonover.*)

Water Injury as Related to Root Rots.—Injury of roots by excessive water appears to have a very important influence on various root rots in which fungi or other organisms play a part. This has been discussed somewhat in Chap. VII under Irrigation in Relation to Citrus Diseases.

A root rot on lemon trees in Australia thought to be induced in part by deficient drainage and stagnant water was described by McAlpine (1899). A species of fungus, *Phoma omnivora,* was found closely associated with the rot. Diseased roots become dark brown to almost black in color. Stevenson (1918) mentions the sudden dying of Citrus trees in Porto Rico as the result of injury produced by too much water at the roots. Associated with this injury was the fungus, *Ustulina vulgaris,* which he believed acted in a secondary way as a wound parasite. Having gained entrance at the ends of the roots killed by water, it works up along some of the main roots and girdles the crown. Soon after the death of the tree, fruiting bodies of the fungus appear as "black carbonaceous crust-like layers, pitted with innumerable openings into the spore sacks." A dry white rot of the roots and trunk follow the invasion of this fungus. The same or a similar species of Ustulina is reported on grapefruit, *Citrus maxima,* in India (Butler 1918). The relation of other diseases to excessive water has been mentiond in Chap. V under Irrigation in Relation to Citrus Diseases.

Control.—The means of prevention of water injury varies with the type of soil and other conditions. On very heavy soils, such as is known as "adobe" soils in California, Thomas (1922) has found that, to prevent water injury, irrigation furrows should not be more than 250 or 300 feet in length. A uniform distribution of water cannot be obtained in furrows 500 to 800 feet in length, since the soil at the upper end of such long furrows becomes water-logged when the soil at the lower end is properly moistened. If the upper end is properly moistened the lower will be too dry. In the former case loss of soluble food occurs by being carried down by the water at the upper end of a long furrow below the root zone and in addition the roots are damaged by water logging. It is also found that the irrigation interval can be lengthened to forty-five to sixty days in such soil with better results than with thirty days, thus allowing for proper aeration of roots. Less frequent and more thorough cultivation can at the same time be done with advantage. These long irrigation intervals obviously do not apply to sandier, lighter types of soil where this kind of water injury does not occur and where more frequent irrigations rather than less frequent are often necessary for the best results. In humid climates where irrigation is not practiced, a good drainage and prevention of high water tables are the main essentials in preventing water injury.

CITRUS NEMATODE

The Citrus nematode, *Tylenchulus semipenetrans*, a small microscopic worm which infests the smaller roots of Citrus trees, differs in its effects from the common root-knot nematode in not producing definite enlargements or knots. E. E. Thomas (1923) of the Citrus Experiment Station, University of California, has carefully investigated the effect of this nematode on Citrus trees. He has shown by experiments with two sets of similar trees in large pots, one set of which was infested with nematodes and the other set kept perfectly free, that the presence of the parasite is distinctly injurious, diminishing the number and causing the death of fibrous roots, retarding the growth of the tops and resulting in small yellow leaves. With 1240 trees in the experiment, one-half of which were infested, it is stated that, without exception, the trees not infested made better and more nearly normal growth than the infested trees. The experiment was continued over a period of four years. For some time after the beginning of the experiment, the infested trees appeared to be as healthy and vigorous as those not infested, but gradually signs of deterioration began to show in the infested trees.

Distribution.—This minute parasitic worm appears to be widespread. The nematode was first observed by J. R. Hodges in southern California and found by Thomas (1913) in all of the principal Citrus districts of California. It was soon after found in Florida and Alabama. It was later reported by Cobb (1914) on Citrus roots grown in Florida, Spain, Malta, Palestine, Australia and South America, and was reported by Trabut (1915) in Algeria and by Byars (1921) in Brazil. This nematode occurs more abundantly on loose sandy soil, but has been found on all types of soil in California.

Symptoms.—Badly infested trees have the appearance in their aboveground portions of undernourishment. The leaves are usually undersized, slightly yellow or mottled and the fruit may also be decidedly undersized when ripe. The whole tree when badly infested is usually stunted and shows a state of slow deterioration. As in most diseases of this kind, other aggravating causes for deterioration are often found along with the infestation of nematodes. There are also frequently other causes that may bring on similar symptoms without the agency of the parasitic worms. Citrus trees, moreover, may have their roots somewhat infested by these worms and still show no apparent injury in the tops, provided they are well cared for as to all the necessary requirements of fertilizing, irrigation and cultivation. It is therefore impossible to judge with certainty whether or not a tree is infested with nematodes by merely examining the top.

Below ground the feeding roots on badly infested trees will be found to be severely injured. If the soil particles cling rather tenaciously to

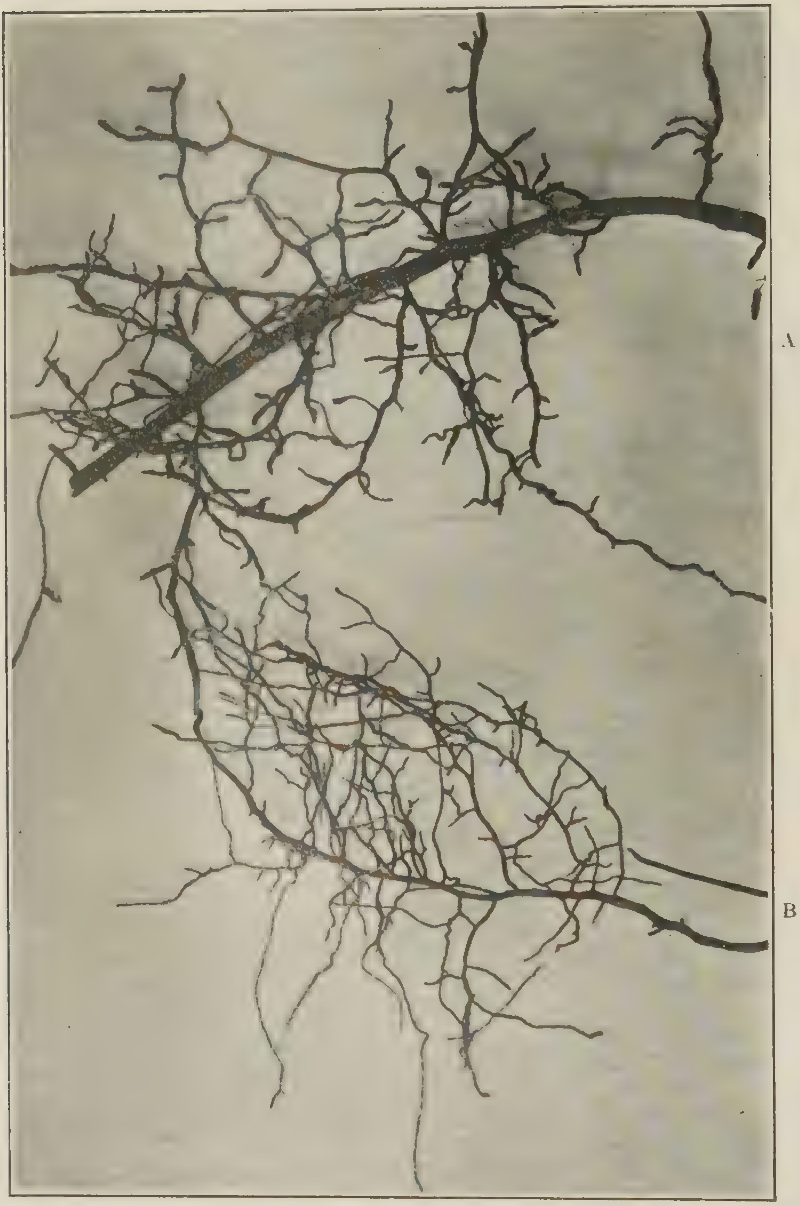

FIG. 14.—Citrus roots showing effect of attack by nematodes: A, showing the fibrous roots slightly enlarged and irregular and with soil clinging tightly to them as a result of nematode infestation, B, showing healthy roots not infested. About natural size. (*Photo by E. E. Thomas.*)

the small rootlets, forming an enveloping cylinder of earth, the presence of nematodes (Fig. 14) may be suspected. The tight clinging of the soil particles is due to the presence of gelatinous material in which the eggs are embedded. A second symptom of the presence of large numbers of nematodes is the ready separation of the cortex from the woody cylinder

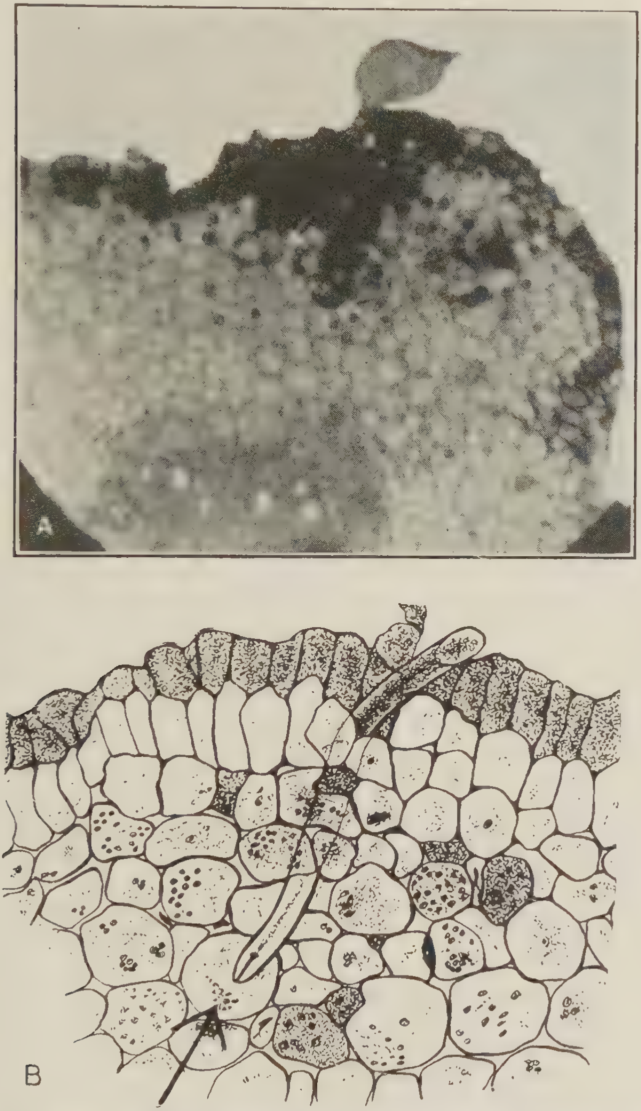

FIG. 15.—A, cross section of a Citrus rootlet showing a female nematode with its head imbedded in the tissue, magnified about 200 times; B, portion of a cross section of a rootlet showing a nematode, probably newly hatched (posterior part cut off), penetrating the tissue, magnified about 300 times. (*After Thomas* (1913, 1923).)

of the root. On healthy roots this separation does not take place so readily. A third indication is the scarcity of healthy growing root tips on badly infested trees. Commonly, under California conditions, various fungi, especially species of Fusarium, are found on the roots in close association with the nematodes. What part they play is uncertain, though inoculations by Fawcett (1923*a*) of one of these species into healthy feeding roots of small Citrus trees of common lemon, sweet orange, pummelo and sour orange failed to show any injurious effects. A convenient method of identification of nematodes is to place the suspected rootlets in a flat glass dish in shallow water after washing away the readily removable earth. The nematodes, if abundant, may then be seen with a hand lens or microscope of low power, preferably a binocular, with their free ends extending out from the surface of the roots (Fig. 15). The males are long and cylindrical in form, and the females are broad and flask-shaped. Each sex is provided with a spear which enables the animal to pierce the tissues of the root.

Means of Distribution in the Soil.—The manner in which distribution of this nematode takes place was also investigated by Thomas. He found in one large tract, planted for the first time, that trees from infested nurseries remained infested when transplanted, while other trees from nurseries not infested were free from nematodes, and this was true whether trees were planted from "balled" nursery trees or from trees with bare roots. It was also found that irrigation water or storm water carried the nematodes from one grove to another. An example was noted where the nematodes were carried for 2 miles by the storm water and infested every grove which lay in the path of this water. They may also be carried on the feet of persons or horses or by farm implements, such as tractors, plows, cultivators, wagons, or anything which transports moist soil from place to place.

Characteristics of the Nematode.—The minute appearance and habits of the Citrus nematode, *Tylenchulus semipenetrans*, were technically described by Cobb (1914) as follows:

> Cuticle naked, transversed by 400 to 500 plain transverse striæ. Neck cylindroid, becoming convex-conoid near the continuous head, which is rounded in front. No lips, amphids, or eye-spots. Spear and œsophas typically tylenchoid. Median bulb ellipsoidal, with valve; posterior swelling pyriform to elongated, without valve. Male tail conoid to the somewhat blunt terminus. Posterior part of the adult female saccate, with wide blunt tail bent toward the ventral side. Vulva in the midst of a prominent ventral suture.

To this description Thomas (1923) adds:

> Both male and female nematodes bear a spear with its acute point in the mouth. This spear is hollow and connected with a narrow tube which passes through the œsophagus to a sucking bulb or pump by which great suction may

be exerted upon the surface of the tissues. The nematode obtains its nourishment by placing the mouth parts on the surface of the rootlet, thrusting the spear into the tissue and drawing out the fluid content of the cell by means of the sucking bulb.

The oral spear of the male *Tylenchulus semipenetrans* is not so highly developed as that of the female. In the male it also seems to deteriorate with age, which indicates that the males are less capable of attacking a healthy rootlet than are the females. Some of the former have been found attached to Citrus roots, but it is possible that they may have entered the tissues which were already broken down by the females.

Because of this method of feeding, the anterior portion of the body of the female is thrust into the growing tissues of the root, the head having been found piercing to a depth of eight or ten cells. The posterior egg-bearing portion of the female remains outside of the root, and the eggs, which are relatively large and thin shelled, are deposited on the outside of the root and are incased in a gelatinous material. The larvæ, when they emerge from the egg, are colorless and often almost transparent. At an early age, the females insert their heads into Citrus rootlets as above described and probably remain in this position throughout their life cycle. A retreat from the root would be almost impossible, since in many instances the body becomes enlarged somewhat after the outside layers of the root have been penetrated.

The stationary existence of the females accounts for the large number of nematodes found on a small area of root. One hundred female nematodes were found embedded in the tissue of a piece of Citrus root 4 millimeters long, while 108 were found on another root section of the same length.

The life cycle of the nematode may be completed in from six to eight weeks, and as each female is capable of depositing a large number of eggs, their rate of increase is very rapid.

The organism attacks the small feeding rootlets of Citrus trees near the surface of the ground and down as far as the rootlets occur, having been found at a depth of 12 feet. *Tylenchulus semipenetrans*, in contrast to the root-knot or garden nematode, *Heterodera radicicola*, does not form knots or enlargements of any kind on the root and does not entirely enter the root. The root-knot nematode attacks a large number of plants and the beet nematode, *Heterodera schachtii*, is often found on plants other than beets, while *Tylenchulus semipenetrans*, as far as known, attacks only Citrus plants. The roots of a great many plants growing in infested Citrus groves have been carefully examined, but in no instance were the Citrus nematodes found attacking any rootlets other than Citrus.

Control.—Up to the present time, no satisfactory method has been found of eradicating the nematode after the roots have once become infested. Thomas carried on a large number of experiments by treating in various ways the roots of infested Citrus nursery trees before planting. The principal substances used, in various concentrations were: mercuric chloride, nicotine sulfate, carbon bisulfide, formalin, potassium cyanide, acetic acid, citric acid, hydrocyanic acid gas and hot water. None of these controlled the nematodes to any extent on these nursery trees except hot water, and that only with time periods and at temperatures too near the danger point for the plant itself. The water had to be 130 to 135°F. for at least 20 seconds before the nematodes were reduced appreciably. At 140°F. an immersion for 1 second began to diminish their number considerably. Beyond 5 seconds at this temperature, however, all the plants were killed. Byars (1921) found that at temperatures above 120°F. for 15 minutes all nematodes were dead. Steiner and Heinly (1922) have shown that nematodes of the genus Mononchus prey upon and destroy such plant-feeding species as *Tylenchulus semipenetrans*, and the possibility of the control of such plant parasitic forms by natural enemies is one of the most promising fields for research to minimize injury from these parasites.

Observations in the orchards in California indicate that, under commercial conditions, fairly healthy trees may be maintained even when Citrus nematodes are known to be present on their roots. Good cultural practices with abundant and proper fertilizing, irrigation and other care will probably maintain profitable trees on good soil, in spite of the presence of nematodes on the roots. Their excessive multiplication in certain cases, with bad effects on the tree, followed by periods of apparent diminution and partial or total recovery of the trees under good treatment, is probably due to unknown factors, possibly parasites, influencing or controlling either the number or severity of the nematodes, or the resistance of the Citrus host. Many growers have been able to grow successful crops in spite of the presence of the nematode by building up the apparent resistance of the tree by proper fertilizing and cultural methods. Under California conditions one important factor appears to have consisted in the use of suitable amounts of bulky organic fertilizers.

INSECT INJURY TO ROOTS

There are a number of forms of insect injuries which result in lesions or effects that are similar in general appearance to lesions produced by organisms. While these forms of injury will not be discussed fully in this publication, some of them will be merely listed and described in so far as they might be mistaken for or confused with other forms of diseases.

Fuller's Rose Beetle Larvæ.—On the large roots of Citrus trees will often be seen irregular surface markings due to the work of the larvæ of the Fuller's rose beetle. These are small white larvæ which give rise later to the well-known beetles that cut portions out of Citrus leaves.

Symptoms.—The markings on the surface of the root are usually quite superficial; they result from the beetles destroying a few layers of cells as they progress over the surface of the bark. These are usually in curved lines (Fig. 16). A scabby brown tissue is formed along the grooves made by the larvæ, and if the grooves are not very abundant, they do not seem to cause any serious effect on the bark. They may, however, sometimes almost completely cover the surface and undoubtedly cause some harm to the tree. These injuries are also harmful indirectly by making it much easier for certain parasitic fungi to enter the tissues of the root.

Control.—As pointed out by Essig (1915), the larvæ, like most pests underground, are very difficult to control. It is pointed out that the adults are unable to fly, and some means may, therefore, be employed in preventing them from crawling up the trunk or branches of the tree. The use of tanglefoot or cotton bands about 2 feet from the ground has been suggested as a protection. Poison spray composed of 3 or 4 parts of neutral lead arsenate in 50 parts of water have also been suggested.

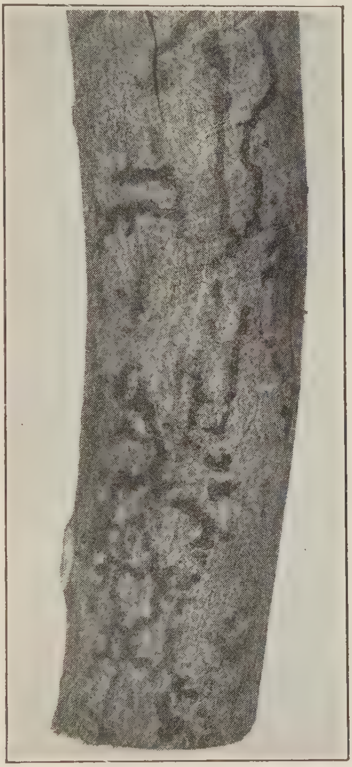

FIG. 16.—Orange root showing superficial markings, thought to be due to larvae of Fuller's rose beetle. These are very shallow grooves.

Blue-green Beetles.—Among the most serious pests in Cuba are the blue-green beetles, *Pachnaeus litus* and *P. azurescens.* The larvæ of these beetles live in the soil and eat the bark from the roots. Strips of bark about the same width as the larvæ are eaten off; these larvæ, when numerous, girdle the roots and cause the death of the tree. They also eat out small patches of the rind of young fruits and cause them to become misshapen. The beetles usually begin to appear at the time of the early rains in April and May and continue in decreasing numbers until October. The injury from the larvæ on the roots is said to show most in the dry season in winter and early spring. The trees turn yellow and in severe cases die. The larva is a footless white grub ½ to ¾ inch long with a light-brown head closely joined to the body. No satisfactory practical method appears to have been used to any extent for controlling these beetles in large trees. For small trees, hand picking or shaking the beetles off upon a sheet stretched under the tree and killing them have been tried with fair success (Cook and Horne 1908).

A number of other insect larvæ feed on the roots of Citrus, and undoubtedly their injuries are important means by which infection of root-disease fungi take place. According to Nowell, long groove-like wounds made by larvæ of the genera Diaprepes and Exophthalmus frequently open up the way for the entrance of the Diplodia fungus on lime roots in the West Indies.

GAS AND OIL INJURY

A certain injury that is sometimes mistaken for the effect of root and bark diseases may be caused by a slow leak of illuminating gas from underground pipes situated near the trees. The roots may be killed and profuse gumming begin at the base of the trunk. The bark may often become ill smelling and finally certain branches begin to wither and die back, or the tree suddenly withers and begins to die. Roots weakened by gas are a prey to certain semiparasitic fungi in the soil.

Considerable injury to the bark, especially at the base of the tree just below the surface of the soil may result from kerosene, distillate or oil sprays that are allowed to run down the trunk and remain in the soil next to the base of the tree. The bark is sometimes killed in large patches or in complete rings around the base of the tree. The entire tree may be killed, or the injury may open up the way for certain trunk- and root-infesting organisms.

Oil which has leaked out from orchard heaters standing under the trees may also result in the death of roots and bark. Sometimes when this oil leaks out on one side of the tree, certain roots will be killed and the injury will spread up the trunk in a strip or segment on one side of the tree, leaving the remainder of the trunk uninjured. Sometimes profuse gumming follows such injury.

CHAPTER IX

DISEASES OF THE CROWN ROOTS AND BASE OF TRUNK

GUMMOSIS IN BARK DISEASES

One of the effects commonly produced by most of the bark diseases, especially on the trunk and upper part of the main roots (known as crown roots) is the stimulation of gum formation. This has led to the use of the term "gum diseases" for a number of these. In diseases like the Pythiacystis gummosis, mal di gomma and Botrytis gummosis, the exudation of gum in large amounts is often one of the most conspicuous features and is often one of the first noticeable symptoms. The death of the large areas of bark, which is often found to have preceded or accompanied this gum exudation, however, is the feature that is most threatening to the life of the tree.

The gum is merely a resultant, and, far from being harmful in itself, appears to serve a useful purpose in flooding the tissues ahead of the advancing parasite and often resulting in halting it or slowing down its progress. Frequently, gum forms under the bark for great distances, 6 inches to a foot beyond the margin of the tissue actually invaded by the parasite. If the physiological conditions for gum formation are favorable, it may form rapidly and accumulate so as to raise the bark from the wood, thus forming pockets at some distance from the seat of the trouble. Finally, the bark breaks under added pressure, and the gum oozes out to the surface.

It is not safe to diagnose the trouble by the gum itself, since its nature and appearance, when exuded to the surface from any cause, are much the same, and since its rate of formation in connection with these bark diseases depends on a number of external and internal factors, such as temperature, air humidity, physiological condition of the plant, etc. (Fawcett 1923*a*, *b*).

Gum may also form as the result of stimuli other than invading organisms. In some cases the gum pockets form without any evidence of dead areas back of them and are surrounded by live tissue on all sides. Such gum formation may frequently result as an effect of fumigation with hydrocyanic acid gas (Fig. 34). In many such cases the gumming is temporary and after a very short period ceases, and the pockets completely fill up with new tissue. This temporary gum formation is frequently mistaken by growers for the first signs of Pythiacystis gummosis, mal di gomma or other diseases of parasitic nature.

Certain chemical substances used as sprays for treatment of the soil or as ant poisons may also induce gum formation. Certain insects may also induce gum; in these cases the gum is probably brought about by secretions of the insects or by organisms gaining entrance rather than to the wound itself. Pure, clean wounds or injuries to the Citrus tissue are not usually sufficient alone to induce gum formation. Many experimental attempts to induce gum formation in Citrus trees by various kinds of injuries, such as cuts, hammer wounds, obstructions placed in the conducting system, constant pressure on the bark, etc., have failed when these injuries were kept free from organisms or chemical stimuli (Fawcett 1923*a*, *b*).

HISTORICAL REVIEW OF GUM DISEASES OF CROWN ROOTS AND TRUNK

The forms of gummosis mentioned in the earlier literature are not described with sufficient accuracy to identify each with certainty. Recent investigations have disclosed that there are at least six distinct gummosis diseases of Citrus. It is believed, however, that most of the more destructive, rapidly developing forms mentioned by various writers were similar to those represented by Pythiacystis gummosis and mal di gomma, which are described later under these headings.

Early Reports of Gum Diseases.—One of the first outbreaks to attract serious attention was that in the Azore Islands, about the year 1834. Judged from the description, it was similar to Pythiacystis gummosis or mal di gomma, as these two diseases are known today. Earlier references to gumming and gum diseases of Citrus are found in a Latin work by Ferrari (1646) and in a publication by Sterbeek (1682). Some few sentences translated from Ferrari are of interest as indicating the state of knowledge and point of view at this early time.

Ferrari writes:

> It is not to be wondered at that humans have disease when plants have them also . . . The tree exuding an abundance of gum burns with its own fire and too often exhausts itself. Such indication of gum flow varies in proportion to the luxuriance of the branches and leaves . . . There are those who cut open the root and insert a stone in the crack to draw out the poisonous material before it gets up into the tree. But this violent treatment is not pleasing to many husbandmen. It is possible for the tree to revive the first year, but it soon weakens and dies. Nothing is believed to be more powerful for sickness of the tree than to bury a dead dog near the roots and this also makes the trees more productive.

Two other early writers on Citrus referred to by Savastano (1910), as mentioning some minor form of gummosis, were Clarici in 1726 and Corrado in 1787.

Speaking of the destructive type of gummosis of Citrus appearing in the Azores in 1834, Fouque (1873) states that sweet orange trees 200 to 300 years of age, which were producing 6000 to 20,000 oranges apiece, were found to be affected with a very destructive form of gummosis. Yellow gum is mentioned as exuding on the trunks near and sometimes beneath the surface of the ground. The trees put on heavy crops of fruit, and the leaves turned yellow and fell off in great quantities. This brief description appears to indicate a form of disease resembling Pythiacystis gummosis.

Gum Diseases in Mediterranean Countries.—A similar type of Citrus gummosis, according to Savastano, was extremely destructive in many Mediterranean localities. It was thought to have been transferred from the Azores to the vicinity of Lisbon, where a destructive gum disease appeared in 1865. It was established in Messina, Italy, in 1863, and was reported near Reggio in 1864. The disease advanced rapidly from Messina, passing into the province of Catania to Acireale. In 1865, it was established at Palermo and raged severely there until 1870. In all the Sicilian Citrus orchards, the gummosis was present in such intensity as to constitute a true epidemic which destroyed all the trees. The orchards were later replanted with bitter or sour-orange stocks. In 1870, the disease was established in the region of Genoa. It became scattered (not epidemic) in the orchards of the Naples, the Amalfi and the Gargano regions. Briosi (1878) estimates the damage from gummosis in Italy as $2,000,000 from 1862 to 1878.

In Greece, in Tunis and in Spain, gummosis became distributed in varying degrees of intensity. Briosi refers to its destructiveness in the Balearic Islands, near Spain, in 1871. In more recent years, a similar disease has been reported in the Oasis of Tripoli, in Egypt and in Palestine.

Gum Diseases in South Africa and Australia.[1]—Gummosis was attracting attention in Cape Colony, South Africa, in 1891, and as mal di gomma, or "collar rot," it has been reported by Doidge (1924*b*) as an important disease. In Australia, a destructive gummosis is referred to by Alderton (1884) as occurring in New South Wales between 1860 and 1870, and by McAlpine (1899) as occurring near Sydney in 1867 and in Queensland in 1876. It is reported by Kirk (1885) in New Zealand.

Gum Diseases in the American Continents.—In the United States, records place its appearance at about the year 1875 in California according to Mills (1902) and 1876 in Florida by Curtiss (1888). In Florida, as foot rot or mal di gomma, it attracted serious attention in 1879, following a very wet year, according to Hume (1900). Moore (1881) speaks of its recent appearance, and Swingle and Webber (1896) report it as still gradually spreading. In California, gummosis was a serious

[1] The wide distribution of gum diseases in the Orient is indicated by recent publications by Reinking (1921) and by Lee (1925). See also Geographical Distribution (Chap. III).

trouble in nearly every Citrus locality by 1878. It was spoken of by Garey (1882) as the only Citrus disease of importance at that time. The horticultural literature of this period indicates that the discontinuance of the use of the common lemon, lime and citron as stocks and the general adoption of the sweet orange and sour orange as the principal stocks in California were due to this disease.

Some of the other localities in American continents where gummosis has been an important disease are reported as follows: in Paraguay, by Bertoni (1911); in Brazil, by Averna-Sacca (1917); in Mexico, by Gandara (1910); in Cuba, by Cook (1906) and Cook and Horne (1908); and in Porto Rico, by Stevenson (1918).

Gum Diseases from an Investigational Standpoint.—Viewing the history of Citrus gummosis from the investigational standpoint, Briosi (1878) studied a gummosis in Italy and described a fungus, *Fusarium limoni*, which he considered to be a factor in the development of the disease. McAlpine (1899) regarded a similar type of severe gummosis in Australia as undoubtedly of an infectious nature and referred to the same fungus as the causal agent. His description of the disease indicates that it is similar in character to the form which Pythiacystis gummosis takes on large orange trees in California.

Comes (1891) produced gumming in Italy by inoculation with a bacterial species which he called *Bacterium gummis*. This organism is also mentioned by Averna-Sacca (1917) in connection with gummosis of Citrus in Brazil and by Gandara (1910) in Mexico.

A number of other investigators, among whom were Swingle and Webber (1896), considered the severe gum diseases as probably infectious and due to some organism invading the bark, but little work of an experimental nature with Citrus appears to have been done until recent years. Fawcett and Burger (1911*a*) and Fawcett (1912*c*, 1913*a*) showed that gumming of branches of Citrus in Florida was due to the presence of a fungus similar to *Diplodia natalensis* Evans.

There have been other investigators who concluded that the severe gum diseases in Citrus were due not to the invasion of organisms, but to certain stimuli operating upon the affected parts. Savastano (1884) made a comparative study of gummosis in both Prunus and Citrus and concluded, because the histology was the same in both genera, that gummosis in Citrus arose largely from wounds or traumatism. This conclusion was in agreement with the views of many previous investigators as to gummosis in Prunus. Among these were Sorauer (1872) in Germany, Prillieux (1874) in France and others. Savastano, in a number of papers in recent years on gummosis in Citrus, has modified this earlier view. He has distinguished clearly between mere gum formation as a general phenomenon and gummosis in connection with definite diseases. In one of these later publications (1910) he accepts Comes's conclusions as to the bacterial origin of the definite disease type and concludes that the aggravating conditions or causes influencing the occurrence of gummosis are lack of light, clayey, water-holding soils, level ground as compared to hillsides, excessive moisture about the roots, wounds from grafting or from digging about the roots and so forth. Most of these contributing conditions are those favorable to gummosis due to *Pythiacystis citrophthora*, or mal di gomma due to *Phytophthora parasitica* (Fawcett (1913*b*, 1923*a*).

Still other investigators concluded that organisms are not at all involved in the initiation of gummosis, but that certain conditions within or without the host are solely responsible for the diseases. Smith and Butler (1908) had concluded that none of the types of gummosis in California were of the parasitic origin, but Smith (1915) was one of the first to accept later the parasitic origin of some of the California types of gummosis. Bertoni (1911) in Paraguay appears to have considered psorosis and Pythiacystis-like forms as phases of the same disease and concluded that poor condition of nourishment is the primary contributing cause. Later (1919) be believed that shade was a corrective for gummosis. Grossenbacher (1916) concluded that untimeliness of bark growth in connection with drought and low temperatures was related in some unknown way to gummosis of the mal di gomma type in Florida.

Previous investigations and observations on Citrus gum diseases had led, therefore, to three general hypotheses: (1) that gum diseases were brought about by organisms capable of infecting and invading the tissue under certain contributing conditions; (2) that gum diseases were due to wounds or other external stimuli other than microorganisms acting immediately on the parts affected; (3) that gum diseases arose autogenously, being due to internal derangements of the host brought about by or without the influence of certain factors of the environment acting on the host as a whole.

PYTHIACYSTIS GUMMOSIS

This disease derives its name from the causal agent, the Citrus brown rot fungus, *Pythiacystis citrophthora* Sm and Sm,[1] a soil fungus related to the water molds. It is quite similar to the next form of gummosis, mal di gomma, now known in Florida and Cuba to be due to a form of *Phytophthora parasitica* Dastur (*P. terrestris* Sherb.). These two similar forms of gummosis are the most widespread and destructive of the Citrus gum diseases. The two diseases are so similar when occurring under the same conditions that they cannot be readily distinguished by superficial examination of the lesions. It is only by examination of the diseased tissue in the laboratory by means of bacteriological methods that they may be distinguished with certainty. Comparative inoculation experiments with

[1] *Phytophthora citrophthora* according to Leonian (1925).

the two organisms have shown the lesions to be quite similar except that there is an indication that the Pythiacystis gummosis organism, *Pythiacystis citrophthora*, is more active on the common lemon (*Citrus limonia*) than on the sweet-orange (*C. sinensis*) bark, and that the mal di gomma organism, *Phytophthora parasitica*, on the other hand, is more active on the sweet-orange than on the lemon bark (Fawcett 1923*a*, *b*).

History and Distribution of Pythiacystis Gummosis.—It is now impossible to determine certainly how many of the gum diseases, spoken of in the Historical Review, were of this form of gummosis or mal di gomma. In California this form of gummosis was recorded in 1875 (Mills 1902) and became an important hindrance to Citrus culture, not long after this date, as evidenced by the horticultural literature of that period.

A committee of California Citrus growers appointed to examine the condition of Citrus orchards, stated in 1878[1] that at that time few localities were free from gum disease, which the committee believed was caused by excessive irrigation and unsuitable cultivation. The orchards most heavily flooded with irrigation water, especially on heavy soils, were found to be the most severely affected. Irrigation by flooding was a common practice at that time, and it was soon found that the lemon (on lemon roots) was peculiarly sensitive to moisture and that when water was left standing about the base of a tree decay readily set in.[2]

A leading nurseryman (Garey 1882) of that period regarded gum disease as the only Citrus trouble of importance.

Of the four Citrus stocks commonly used at that time, sweet orange, lemon, lime and citron, the lemon and the lime were found by Garey to be the most fatally affected. He advised the use of the sweet-orange stock, but did not mention the sour orange which was introduced at a later date.

Sweet-orange stock, though much less susceptible than lemon, was also frequently affected with gummosis. This fact drew attention to the sour-orange stock which had been used successfully in southern Europe and in Florida to replace trees affected with mal di gomma. This resistant stock only gradually came into use as a preventive of gum disease in California. Very little attention appears to have been given to the value of the sour orange as superior to sweet in its resistance to gum diseases, in California, until about 1885.

In the light of our present knowledge of varietal susceptibility of Citrus to gum diseases and of the part played by heavy soils and by excessive irrigation (especially flooding on heavy soils), the failure experienced with lemon stocks, the dying of trees on heavy soils but not on lighter soils and the early discontinuance of the use of lemon, lime and citron as stocks would now appear to have been due to the presence and attack of gum-disease organisms, especially *Pythiacystis citrophthora*.

---

[1] *Southern California Horticulturist*, vol. 1, p. 115, January, 1878.

[2] *Southern California Horticulturist*, vol. 2, pp. 83–86, March, 1879.

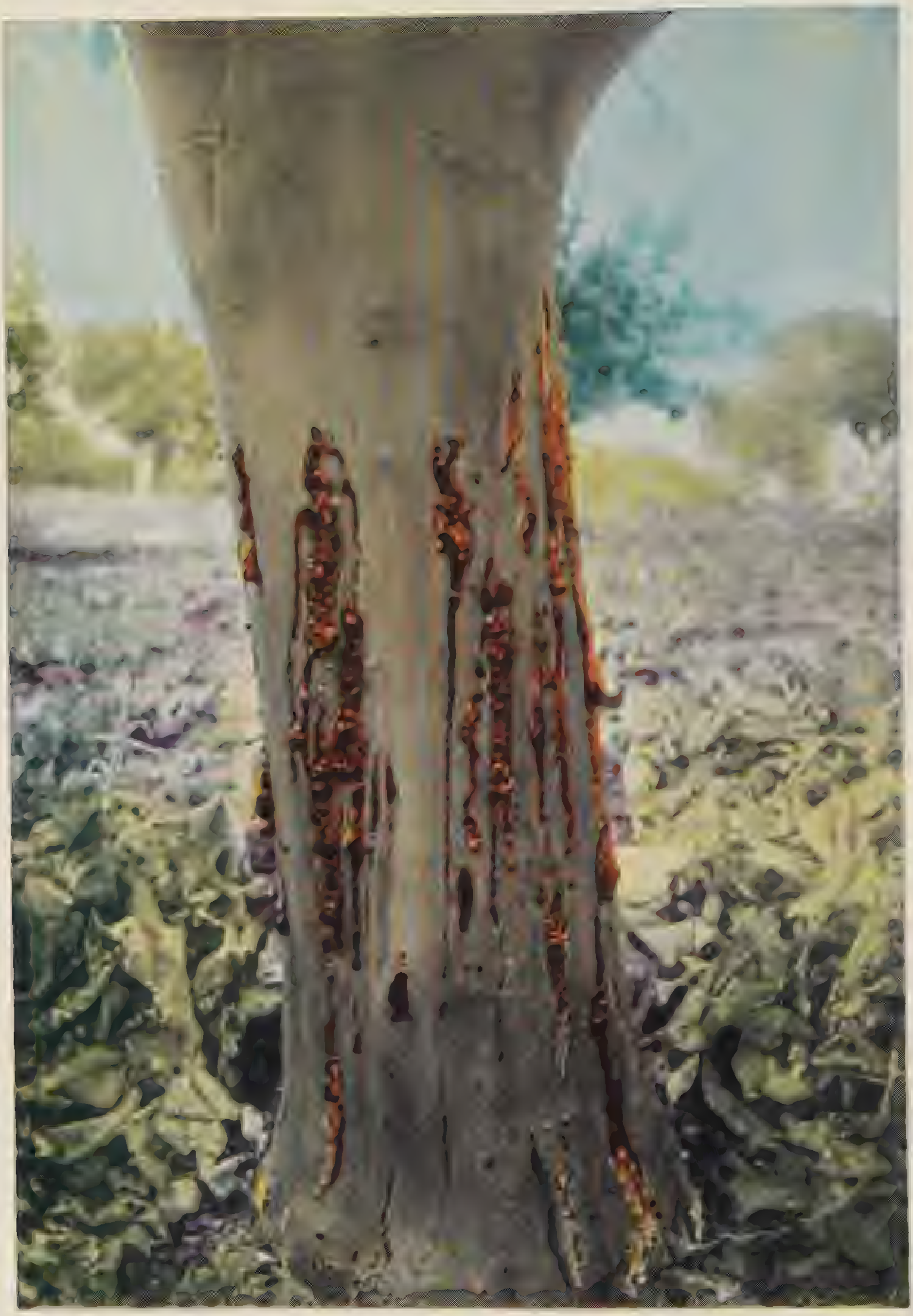

FIG. 17.—Pythiacystis gummosis or brown-rot gummosis due to *Pythiacystis citrophthora*. Showing copious gum formation accompanied by death of the bark on a lemon trunk as a result of rapid development from several infections near the soil surface. On heavy soil, California.

(*Facing page* 127)

A gum disease quite similar to this one or to mal di gomma has been reported in nearly every important Citrus-growing region of the world. A similar disease has been reported in recent years in New South Wales by Darnell-Smith, in Western Australia[1] by Stoward and in Egypt by Fahmy (Brown 1924). In Italy and Sicily, a gum disease occurs with superficial symptoms similar to those of Pythiacystis gummosis or mal di gomma (Fawcett 1925). It is mentioned by Petri (1924) as causing severe damage to Citrus in Sicily and Sardina. He believes it to be associated with a fungus possibly allied to, or identical with, *Pythiacystis citrophthora*. A Citrus grower of Palestine recently visiting California reports that a disease with symptoms like Pythiacystis gummosis is the most destructive disease in his country, having killed as high as 20 per cent of the orange trees in many orchards. The trees are on sweet-lemon stock grown under irrigation by flooding in basins around the tree trunks (see also Historical Review of Gum Diseases and map, Fig. 26).

Symptoms.—Pythiacystis gummosis affects, for the most part, the trunk near the soil and the larger main roots. It may occasionally be found on branches higher in the tree.

On the lemon, *Citrus limonia*, (the most susceptible variety), patches of bark are killed and often large quantities of gum are exuded (Fig. 17). Infection usually starts at the base of the trunk or on the crown roots and works rapidly both upward and laterally. The bark is killed not as in psorosis and shell bark merely in the outer cortical layers, but entirely through to the wood, thus including the cambium. A thin layer of wood tissue only about 1½ inches thick is visibly affected unless secondary organisms enter. The bark above the soil is not softened as it is in the early stages of Botrytis gummosis or Sclerotinia gummosis, but remains firm and intact until drying causes it to shrink and crack longitudinally (Fig. 18*b*). Below the surface of the soil, secondary organisms frequently set up fermentation and moist decay.

On the bark of old orange trees and other partially resistant varieties the progress of the disease is often soon arrested and the lesions tend to become self-limited. The loss of large patches of bark is followed later by a gradual yellowing and dropping of leaves on the branches leading out from the portion of the trunk affected.

T. Fahmy states that in Egypt, on badly affected trees budded on citron stocks, the lesions may start to form at the crown roots and frequently progress up into the branches; the underlying tissue of the bark is firm and stained brown to yellow and under moist conditions the woody tissue at the base of the trunk rots. Where the tree is branched near the ground, the disease may progress so far as to cause the death of one or more of the principal branches.

Early Stages on Lemon Bark.—Although these are the main characteristics of the disease as seen on superficial examination, there are many special features which appear when more careful study is given to its development under various conditions. In the earlier stages the exuding gum is usually the only external symptom readily observed. By lightly scraping the bark at this time the margin between the sound and invaded tissue is shown indefinitely only by a gradual shading of the normal green color to a drab. The bark is not softened, but remains firm. Only after a considerable time does it shrink and crack longitudinally (Figs. 18, 19).

---

[1] See recent investigations by Carne, Jour. Roy. Soc. W. Australia **12**: 13-41, 1925.

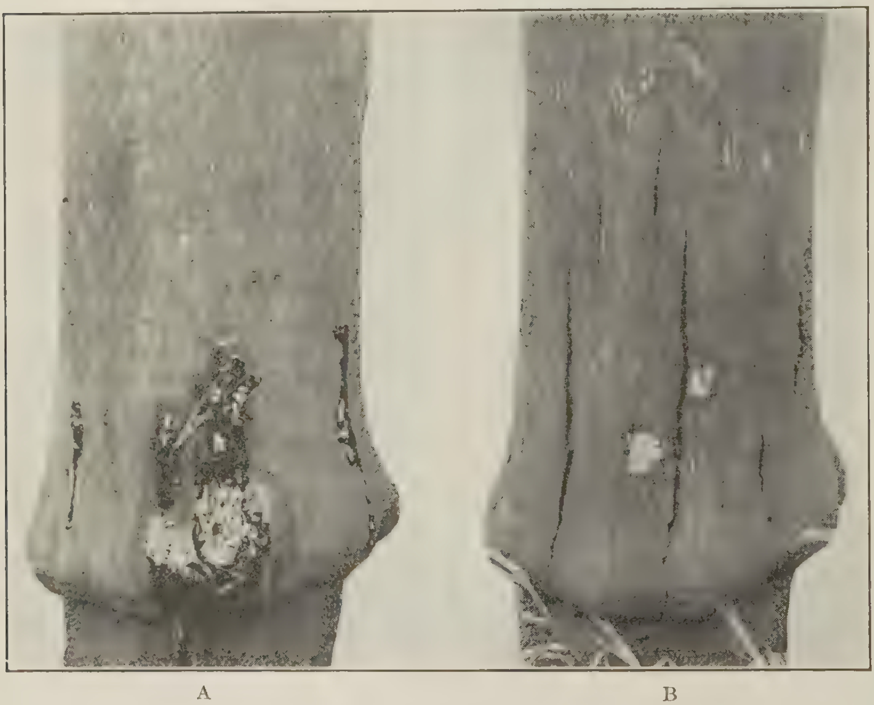

Fig. 18.—Pythiacystis gummosis on lemon tree: A, tree inoculated February 27 and photographed April 24, the large amount of exuded gum indicates the rapid development of a gummosis lesion; B, same tree 15 months after inoculation, the gum first formed having been dissolved by winter rains, and the dead bark having dried and shrunken. Gum was exuding farther around on (B) at this time.

The Invaded Region and Gummous Zone.—On healthy, rapidly growing lemon trees under average California conditions in the coast regions, the area of killed and darkened bark, which is elliptical or irregular in outline, is usually 5 to 10 inches in vertical length and half that in width when the gum first becomes apparent. By that time the fungus has been invading the tissue usually for a period of from two to four months. The removal of the bark at this time will show that the margins of the invaded zone near the cambium are about coextensive with that seen on the surface. The upward and downward extension in the bark from

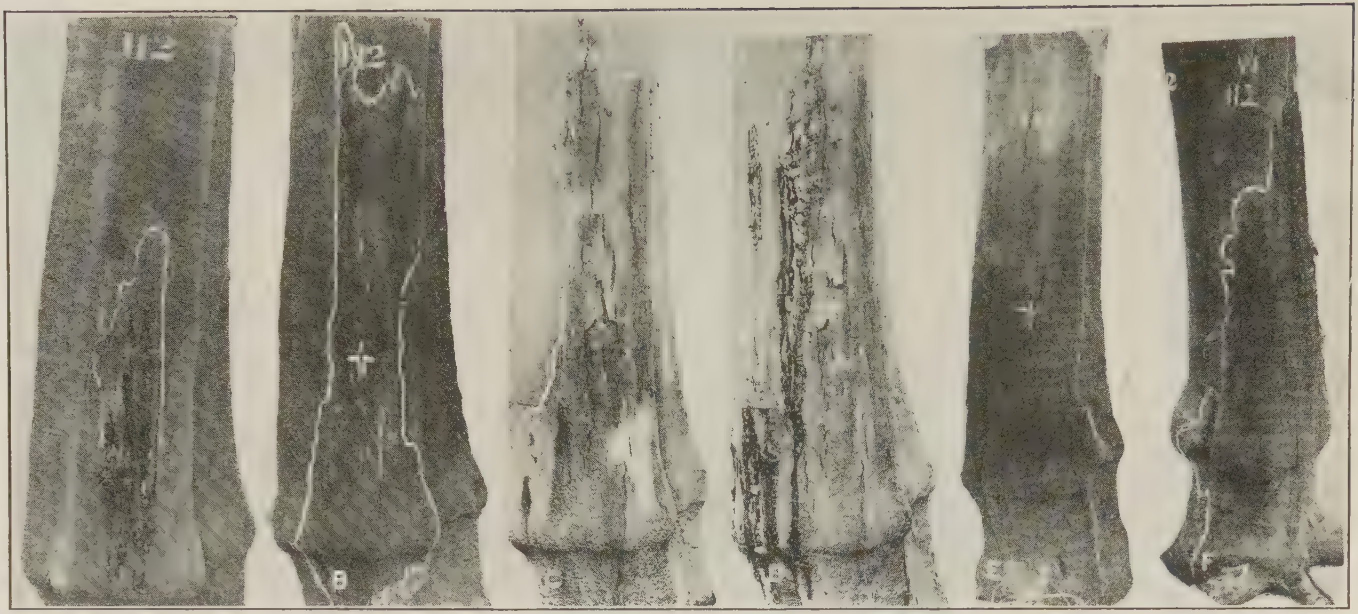

Fig. 19.—Progress of Pythiacystis gummosis over a period of three years as a result of inoculation with *P. citrophthora*, the severity of the disease being increased by the addition of *Fusarium sp.* A, Exuded gum and extent of invaded zone within the chalk line, 5 months after inoculation. Arrow indicates point of inoculation. B, Extent of the lesion on same tree, 9 months after inoculation. The infection has extended downward nearly as far as upward. C, Extent of lesion and cracking of bark more than 13 months after inoculation. The gum of figures A and B has been dissolved by rains. D, Large quantity of exuded gum and a great enlargement of invaded zone and cracking of bark, about 17 months after inoculation. E, Further cracking of dead bark nearly 2 years after inoculation. The gum of figure D has been dissolved by further rains. F, Trunk on opposite side from figure E, on same date. Only a small strip of live bark here remains, which was later invaded, this resulting in the death of the tree.

the point of infection is usually many times greater than the lateral extension.

In an irregular zone or band surrounding an actively invaded area, the cambium layer shows an influence extending from the margins of the dead bark. There is a production of clear, watery gum which seems to originate in the region of the embryonic wood among the live cells without at first any apparent fermentation or decay (Fig. 20). This region at the cambium, not yet darkened, beyond the invaded portion, will be spoken of as the "outer gummous zone." It may in time extend considerable distances at the cambium upward and downward and smaller distances laterally from the margin of the invaded zone. It has been traced for 2 and 3 feet upward. The extent of this outer gummous zone varies with the age and rapidity of development of the disease lesion, the condition of the tree, etc.

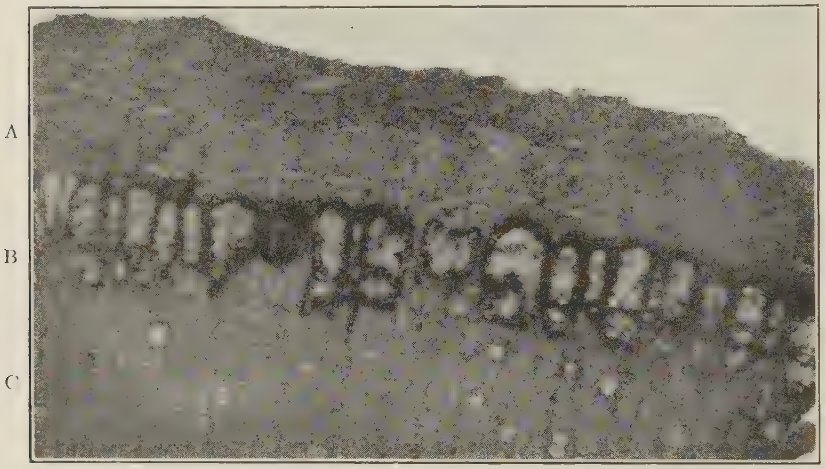

Fig. 20.—Cross section through a lesion of Pythiacystis gummosis viewed as if looking downward with bark (A) at top of the illustration and wood (C) at the bottom. A region of gum formation involving the recently formed wood or xylem, the cambium and a small portion of the phloem is shown at (B). (*Photo contributed by J. T. Barrett.*)

The inner surface of the bark in the invaded zone in a lesion of considerable size varies in color from Ridgway's (1912) mineral brown to burnt umber or fawn, and the same discolorations will be found on the surface of the wood just at or beneath the cambium. The discoloration does not extend far inward, usually only 1/12 to 1/5 inch (2 to 5 millimeters) into the woody layers. The cambium region in the gummous zone is chamois to yellow ocher in color, gradually fading at the margins into the normal color of the sound woody surface.

Frequently, when the bark is irregular in contour, gum pockets 1 to 2 inches in length will be formed. The gum accumulates near the cambium and by pressure separates the bark from the wood at certain places, forming definite pockets. The pressure is usually relieved by a break in the bark before the pockets become large. A few deeper gum pockets of considerable size have also been found, situated in the gummous zone beneath layers of wood 1/8 to 1/4 inch (3 to 6 millimeters) in thickness, with accumulations of gum under pressure. The gum, which is watery and clear when first formed, hardens as it comes to the surface, apparently through loss of water, and finally becomes brittle (Fig. 17). On the surface the hardened gum is usually mahogany to chestnut in color. The gum accumulates on the surface in long narrow ridges or in oval masses, or runs down and collects in masses on the soil, according to the rapidity of its formation and the dryness of the air. During periods of heavy dews and rains it gradually dissolves and disappears.

The invading hyphæ frequently die out rapidly behind the marginal fringe of advance, and quite often they die out completely over a part or all of this outer margin, so that the progress of the disease is checked or entirely arrested. Such cases are often found among trees having some power of resistance, especially among orange and grapefruit trees, or where the weather conditions subsequent to infection become unfavorable to the parasite.

Later Stages.—In trees on which the disease has been present for a long time, the dead bark over the invaded portions dries, shrinks and cracks (Figs. 18, 19). The larger cracks are mostly vertical, with smaller horizontal cracks. A thin layer of the wood immediately under the invaded bark will usually be found to be infiltrated with hardened reddish-brown gum which protects the under layers from rapid drying and, to a considerable extent against the entrance of wood-rotting fungi.

The effect on the foliage often does not appear for many weeks or even months after the bark has been killed. The leaves on the side of a tree badly affected, or all over a tree that has been girdled, first fade to a yellowish green, and later become yellow or chlorotic. The principal veins and the regions next to the veins are often the first to turn yellow, presenting a yellow network with the rest of the blade also yellow, just the opposite of foliocellosis. Leaves then begin to fall, leaving bare branches; older leaves soon turn yellow all over and may show irregular brown spots before they fall. The green bark on the twigs also turns yellow later and smaller twigs die at their tips. According to Ridgway's chart, normal lemon leaves may be cerro green, while the leaves on affected trees have stages showing yellowish oil green, Pinard yellow and finally buff yellow.

Characteristics of Disease on Sweet Orange (Citrus sinensis).—On old sweet-orange trees, the invaded areas are usually less extensive and more restricted laterally than on the common lemon (*C. limonia*). There is usually less gum than on the lemon. In the orange there is a greater tendency for the invading fungus to die out and for the invaded area to become self-limited than in the lemon. Frequently, the invaded areas on old sweet-orange trunks extend upward from the soil surface as narrow tongues of killed bark. On younger orange trees and frequently on older ones growing vigorously on heavy clay soils, the disease may assume much the same characteristics as it does on the common lemon.

Causal Agent.—The causative agent in the destruction of the bark and the stimulation of gum on the part of the tree in connection with this disease was shown by Fawcett (1913*b*) to be the soil-inhabiting fungus, *Pythiacystis citrophthora*, previously shown by Smith and others (1907) to be the cause of brown rot of Citrus fruits. The discovery was made as the result of a long series of experiments with many repetitions, as follows:

1. Inoculation into sound trees with bits of diseased tissue transmitted the disease with all its characteristic symptoms. It was found, however, that only the diseased tissue from the marginal fringe of the killed bark of active lesions was capable of transmitting the disease. Tissue from places back of this margin toward the center of large lesions or from the outer gummous zone was incapable of inducing gummosis.

2. Culture tests made from pieces of bark from various places within and outside of the killed portion of the lesions revealed the presence of *Pythiacystis citrophthora* only at the marginal fringe between what were subsequently called the "invaded zone" and the surrounding "gummous zone."

3. Inoculations were made into the bark of sound trees with pure cultures of this fungus and the disease was induced with all its characteristic symptoms (Figs. 18 and 19). Many repetitions gave the same results. Inoculations with large numbers of other fungi and bacteria found in the older portions of the invaded zone failed to cause the disease. It was therefore found that only diseased tissue from the marginal fringe of the invaded zone was capable of transmitting the disease, because in this portion only did the causal organism remain alive; also that the outer gummous zone was a transmitted effect extending far ahead of the actual fungus invasion.

4. The same fungus was reisolated forty times from twenty of the cases of gummosis produced by inoculation and again found to be alive only at the outer margin or fringe of the invaded zones, just as in the naturally occurring cases previously mentioned. The time elapsing between inoculation and reisolation was from one to twelve months in different tests, and the fungus was recovered at distances as great as 20 inches (50 centimeters) or more from the original point of inoculation.

5. Inoculations were made also with bits of lemon fruits affected with brown rot and with the fungus, *Pythiacystis citrophthora*, isolated from diseased fruits, with the same results as those obtained by the use of bits of diseased bark or cultures isolated therefrom.

Characteristics of the Fungus.—The characteristics of this interesting fungus are described by R. E. and E. H. Smith (1906) as follows:

> Mycelium in affected fruit sterile, inhabiting the rind and fibrous portions. Internal, except in moist air . . . Fruiting stage found typically in moist soil, in contact with affected fruit (Figs. 123, 124). Sporangia ovate or lemon-shaped, sometimes rounded, considerably elongated, or double, with terminal protuberance; 20 by 30 to 60 by 90μ, average 35 by 50μ. Produced in great abundance under favorable conditions. In water dividing quickly by internal division into five to forty (usually about thirty) swarm spores, which are immediately set free and discharged through a terminal pore. Swarm spores 10 to 16μ in diameter, at first elongated, becoming rounded; with two lateral cilia 30 to 40μ in length. Actively motile when discharged, soon coming to rest and germinating. Fungus abundant in winter and spring in southern California lemon orchards and packing houses, causing serious losses (Figs. 21–23 and compare with Figs. 27–29).

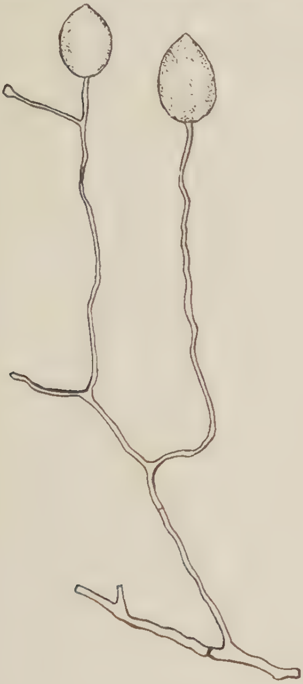

FIG. 21.

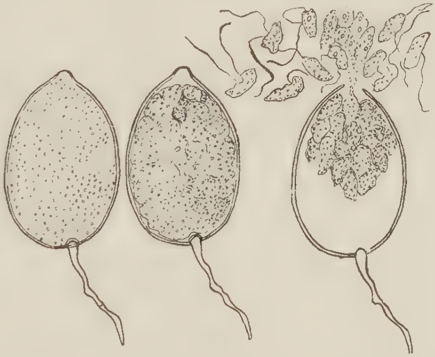

FIG. 22.

FIG. 21.—*Pythiacystis citrophthora:* A, Spore-bearing hyphae and sporangia such as form in films of water on the surface of the soil, magnified 180 diameters. (*After Smith, et al* (1907).)

FIG. 22. Showing sporangia with development of swarmspores of *Pythiacystis citrophthora.* Each swarmspore has two cilia by which it swims about in films of water as if it were a low form of animal. When one of these swarmspores comes in contact with the damp surface of Citrus bark, or fruit, it soon comes to rest, loses its cilia, germinates and sends hyphae into the tissue. Magnified 400 diameters. (*After Smith and Smith* (1906).) (Compare with Fig. 28.)

Isolating and Growing the Fungus.—Normal sporangia may be produced readily by growing the fungus on moist clay soil or in dilute prune juice from which bits of hyphæ are later transferred to shallow dishes of water. In order that the spores may swarm it is necessary to have continuous water films. One of the best culture media in which to produce vegetative hyphæ is dilute prune juice, in which vigorous profusely branched hyphæ form a mycelial mass suspended in the liquid. The removal of bits of this mycelium to shallow dishes of water will produce, usually in 48 hours at ordinary room temperatures, a fringe of more slender hyphae with formation of sporangia and motile zoöspores (Smith *et al* 1907).

The method which has been found useful for determining the fungus is to cut out with a sterile scalpel small bits of diseased tissue from the margin of the invaded portion of bark or fruit and place them in tubes of corn-meal agar (Fawcett 1923*a*). After two to four weeks' growth on this medium, the characteristic sporangia are formed. By this method, pure cultures are readily obtained, and when other organisms are present as contaminations, *Pythiacystis citrophthora* can be identified by its characteristic sporangia. The Pythiacystis may readily be separated from contaminating fungi by transferring the mixed culture to a jar of water containing lemon fruits. The Pythiacystis will enter the fruit and produce brown rot, leaving the associated organisms behind. It may then be isolated more easily as a pure culture from bits of infected fruit.

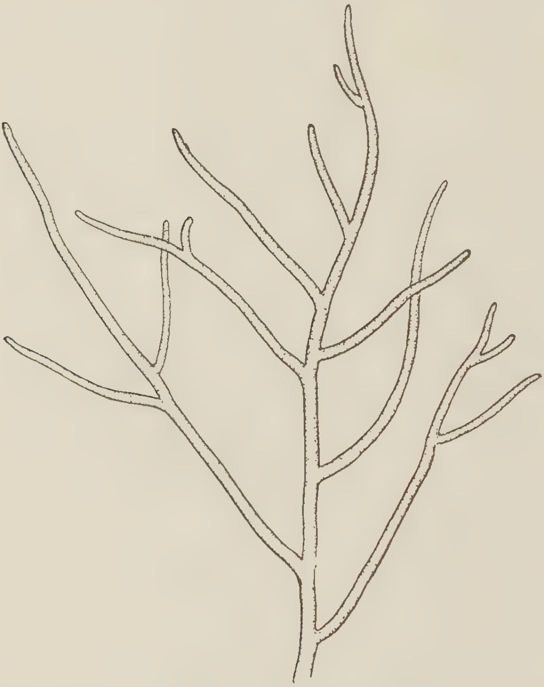

FIG. 23.—Portion of mycelium of *Pythiacystis citrophthora* grown in nutrient agar plus 0.5 per cent glucose, magnified about 150 diameters. Compare with corresponding portion of mycelium of *Phytophthora parasitica* of Fig. 27.

Much variation in type and shape of sporangia are produced on moist soil and water cultures.

Pythiacystis Similar to Phytophthora.—In the strains of Pythiacystis so far isolated from diseased Citrus bark and similar to the ordinary brown rot fungus of the lemon, no sexual or perfect spore-producing organs have yet been found. In a few instances other Pythiacystis-like strains have been found, however, on deciduous fruit trees and on lemon fruits that have developed a perfect stage which appears to have the characteristics of Phytophthora. The *Phytophthora parasitica* first isolated from Citrus in one locality in California and later in Florida and Cuba (Fawcett 1915*b*) has sporangia and swarm spores so similar to Pythiacystis that it was at first mistaken for that species. In its method of growth, also, the hypha and mycelia of *Pythiacystis citrophthora* have marked similarity to certain species of Phytophthora, especially *P. parasitica* (Figs. 27, 28). It seems fairly certain that if the sexual stage of the Pythiacystis fungus were known, it would show the fungus to be a Phytophthora (Fawcett 1920).[1]

Contributing Conditions.—A study of the external conditions under which Pythiacystis gummosis is most likely to become severe, taken in conjunction with experiments with the fungus, indicates that the important factors are: (1) abundant moisture in the soil in contact with the bark over a sufficiently long period, (2) favorable soil and air temperature, (3) wounds or other injuries to the bark, (4) susceptibility of varieties of stocks and scions or both. A condition which in practice often contributes most to infection in the orchard is that of deep planting, or the accumulation of soil next to the trunk of the trees. Under these conditions, there is greater surface of the bark in contact with the soil, and the bud union, if low, becomes buried. The bark over the union between stock and scion is usually especially susceptible to infection, probably because of frequent irregularities of growth, suckering, etc.

Injuries.—Injuries, although aids to infection, are not necessary if the two first-named conditions mentioned above are simultaneously fulfilled. Injuries, especially below the soil surface, aside from inducing infection more readily when the conditions of moisture and temperature are suitable, may also aid in bringing about infection where the soil moisture is not excessive by conveying the organism into the moist inner bark tissue where penetration can start without the addition of further moisture. Wounds or injuries, therefore, while not absolutely necessary for the entrance of the parasite, when sufficient moisture is present, are probably the only means of entrance when the moisture content of the soil immediately in contact with the bark surfaces is not excessive.

---

[1] Leonian (1925), as a result of comparative tests with a large number of strains of Phytophthora, concludes that *Pythiacystis citrophthora* should be known as *Phytophora citrophthora.*

Moisture.—The severe form of Pythiacystis gummosis is most frequently found under California conditions on lemon trees, where they are budded low, on sweet-orange or other susceptible stocks which are growing on heavy soils, and is especially prevalent in the coastal sections. Heavy clay soils, being much more retentive of moisture than lighter, more open soils, furnish the means by which water films may remain adjacent to the bark for periods of time sufficient to permit infection by the fungus parasite.

The great prevalence of fogs and the comparatively slight fluctuations of temperature in the coastal sections also decrease the rate of evaporation in the soil that has become excessively wet during irrigation or rain. In the interior valleys, even the same type of soil usually dries out more quickly after irrigations and rains. If the drying out is rapid, there is not sufficient time for infection; if drying is slow, however, the time may be sufficient for the penetration of the fungus hyphæ. A low bud union increases the liability to attack, because the lemon bark above the union may be infected either by the fungus parasite growing directly into it from excessively moist soil or by the germination of spores splashed by raindrops, especially when wounds are present. If lemon trees are budded high on sweet-orange stocks, they will have somewhat more chance to escape, because this stock is somewhat more resistant than lemon; it is, nevertheless, susceptible to the disease, especially under favorable conditions for the parasite. If budded high on sour-orange stock, however, there is practically no danger of the disease even under bad water conditions, because of the great resistance of the sour-orange stock.

Temperature.—Within certain limits, temperature appears to be another important factor, especially in the growth of the fungus and its formation of spores and in the infection of the host as a result of the germination of these spores. As has been previously shown (Fawcett 1921*a*), a temperature somewhere near 77°F. (25°C.) appears to be about the optimum for a sustained growth of the fungus hyphæ in cultures, and very little growth takes place above 86°F. (30°C.). If, as seems probable, similar relations hold for the growth of the fungus in the bark, this explains the fact that the disease progresses slowly during hot periods, and also that its progress is sometimes completely checked, the fungus being killed out in many instances. This is especially true in the interior valleys, in the case of parts of lesions entirely above the soil surface. Here, the temperature of the bark frequently becomes many degrees above the death point of the fungus. Recent experiments (Fawcett 1922*a*) have shown that a temperature of 115°F. for one minute in water is sufficient to kill the spores of this fungus on infected fruits, and temperatures much lower than this for greater lengths of time will undoubtedly have the same effect.

In line with this possibility is the observation that the rapid enlargement of invaded areas usually continues much later in the year or may proceed throughout the whole year in the cooler coastal sections, while the activity and progress of the disease are usually limited to the winter, spring and early summer in the hotter interior sections.

Susceptibility of Different Species and Varieties.—Among the Citrus species and varieties that have been tested, the common lemon (*Citrus limonia*) has the lowest resistance to Pythiacystis gummosis, and the sour orange (*C. aurantium*) the highest. The sour orange usually is so resistant to Pythiacystis attack that, even when the most favorable conditions are given by inoculation in wounds, there is only a slight gumming with rapid healing of the wounded tissue and with total failure to produce a diseased lesion. The sour orange is also highly resistant to all other infectious gum diseases of importance. Of the forms which have been most used for stocks in California, the trifoliate orange (*Poncirus trifoliata*) probably stands next to the sour orange in resistance and the sweet orange next to the common lemon in susceptibility, with the grapefruit (*C. maxima*) and the rough lemon standing between these two. Because these stocks are grown from seed, there is a possibility of variation in resistance within each variety due to differences between strains, and observations have suggested that such variation actually exists. The following observations, however, indicate the relative resistance of some of the common varieties.

A block of 5000 sweet-orange seedlings about two and one-half years old, growing in nursery rows on medium-heavy clay loam soil, had been planted adjacent to a block of 15,000 sour-orange seedlings of the same age and receiving the same care. All the trees had been irrigated rather frequently and heavily. Four representative rows of sweet-orange trees showed 241 out of a total of 827 trees affected, or about 29 per cent. A thorough search in the block of sour-orange trees failed to reveal a single affected tree.

Differences in resistance were indicated further by a nursery of Citrus seedlings about two years old, growing at the California Citrus Experiment Station. The following is the percentage of gummosis which was recorded by W. M. Mertz:

Species	Number of trees	Per cent with gummosis
Citrus aurantium, sour orange	1000	0.3
Poncirus trifoliata, trifoliate orange	1000	1.0
Citrus maxima, grapefruit	1000	2.5
Citrus sinensis, sweet orange	2000	10.00

Inoculation experiments in various stocks have confirmed these observations (Fawcett 1923*a*, *b*).

Citron, *C. medica*, also appears to be quite susceptible to this disease. According to T. Fahmy the citron stock has been used most generally in Egypt and appears to be susceptible there to Pythiacystis gummosis. When orange trees on stock are planted deep, as they often are, the citron stock is usually attacked by Pythiacystis gummosis and later rots, while the more resistant orange roots grow out from above the bud union and often keep the tree alive. The sweet lime is also susceptible to this or a similar disease in Palestine, where, according to recent reports, 20 per cent of the Jaffa orange trees on this stock, when irrigated by flooding around the tree trunks, have been killed out.

Limes were also found to be quite susceptible to this disease in the early days of the Citrus industry in California (see p. 126).

An Example of a Typical Outbreak.—The following is a concrete example of a set of conditions that resulted in a serious outbreak in a 5-acre, six-year-old lemon orchard at Whittier, Cal., in 1914, on medium-heavy clay soil.

The season had been one of unusually heavy rainfall. In March, a volunteer crop of barley was cut while green and thrown around the trees in contact with their trunks. This operation was followed by heavy rains and cloudy days. In May, ninety trees with brown rot gummosis in various stages were discovered. The lesions appeared to have started at various places below and above the surface of the soil. Some of those above the surface had started at places where water sprouts had been broken off, but many appeared to have started in sound, uninjured bark. The barley piled around the trunks had undoubtedly aided in retaining films of water for a sufficient time to permit germination of the spores and the penetration of the hyphæ. All the diseased trees were successfully treated, and a description of the method and results will be found under the heading of control.

Fusarium as a Secondary Aid in the Development of Pythiacystis Gummosis.—A species of another fungus, *Fusarium sp.*, frequently accompanies and is closely associated with *P. citrophthora* in the diseased tissue. Fusarium has been mentioned frequently in the literature as having some possible relation to certain types of gum disease. Briosi (1878) and McAlpine (1899) concluded that *F. limoni* Briosi played an important part in mal di gomma in Italy and in Australia. Earle and Rogers (1915), though not able to produce gummosis by inoculation with Fusarium, believed that under certain conditions it was probably a factor in a certain type of gum disease in Cuba. The present writer also had previously found species of Fusarium repeatedly associated with mal di gomma or foot rot in Florida, but inoculations with them had given negative results.

Experiments have indicated that the severity of this disease is increased by adding Fusarium along with *Pythiacystis citrophthora* at the time of inoculation. The characteristics of the disease, however, were the same as when the Pythiacystis was inserted alone, while inoculation with Fusarium alone failed to produce this type of gummosis. Pure Fusarium inoculations caused only a slight killing of a narrow layer of tissue along the cut with only slight gumming in a few cases, and later resulted in a cracking of outer layers of bark around the cut. Otherwise the effect was not different in either case from that produced in the inoculated cuts used as checks on the same trees.

Control of Pythiacystis Gummosis.—Methods of prevention and control based directly on a knowledge of the cause and development of the disease have been worked out experimentally by many trials.

Prevention.—As previously pointed out, the causative fungus usually infects the bark at or below the surface of the soil. The roots of a susceptible variety are more resistant than the bark of the trunk. Some of the principal conditions of infection are: (1) excessively wet soil in contact with the trunk, as a result of improper irrigation and drainage, or long periods of continuous rains; (2) deep planting, or soil piled up around the trunk, especially when it is highly retentive of moisture; (3) injuries to the bark at the base of the tree, especially in wet weather; (4) susceptible stocks.

The most successful method of prevention for new plantings on heavy soils is obviously the use of sour-orange or other resistant stocks of good quality budded high. This method was employed in Italy after the orchards were killed out by gummosis and has since been used successfully for heavy soils in Florida and California. Sweet-orange or other less resistant stocks may be employed, if proper care is exercised on light soils or soils not retentive of excessive moisture.

The method which has been found effective and is now in common use in preventing infection on somewhat susceptible stocks is as follows: The soil is pulled back from the base of the tree to expose the top of the first main roots and is left in a circular ridge to exclude irrigation water as much as possible from the depression next to the trunk. If the depression occasionally becomes filled with water, the result is usually not so serious as when the soil is against the bark, because the water after a rain soon percolates into the soil. Except under very moist weather conditions or in very humid climates, with most Citrus soils, the length of time that water would stand in such a depression is usually not sufficient to produce infection. This pulling away of the soil is most important on the heavier clay soils, while on looser sandy soils this practice is not so necessary.

As an additional means of prevention, the bark at the base of the trunk is painted with Bordeaux paste or other non-injurious fungicide after pulling the soil away (Chap. VI).

The practice of merely loosening the soil by digging about the base of the tree without pulling the soil away, if no injuries are produced, probably helps to prevent infection by hastening the drying out of the soil. This practice may, on the other hand, if carelessly performed, result in injuries to the bark and aid in the entrance of the organism later, or actually introduce it with soil from the tools into the inner bark tissues. Any agencies, such as gophers, field mice, rabbits, or tools used in orchard operations that produce injuries to the bark, may contribute to the ease of infection by the fungus parasite. Infection, however, appears to take place frequently through the sound uninjured bark when moisture is sufficient.

For the control of Pythiacystis gummosis, in countries like Egypt or Palestine where irrigation water was formerly applied directly around the tree trunks, furrows or basins are now dug on four sides of the tree at a distance of 3 feet or more from the trunk, according to the size of the tree. The irrigation water is allowed to run into these furrows or basins, but is not allowed to get into the center where the tree stands. The soil is also pulled back from around the base of the trunk so as to expose the crown. This method has been effective in preventing a large percentage of the disease in Egypt, according to T. Fahmy, and also in Palestine, according to a prominent grower from that country.

Examples of Prevention.—The following experiment on fifteen-year-old lemon trees at Chula Vista, Cal., has been reported by Prizer (1915). The trees had low bud unions and the soil, a heavy "adobe," had not been carefully pulled back from the base. Ten per cent of the trees had new lesions on the trunk the year before. Thirty-six per cent of the trees had already been killed by the disease and were missing. The trunks, in two rows containing eighty-one trees, were painted with Bordeaux paste in the fall of 1913, and two other rows next to them containing seventy-two trees were left unpainted as controls. During the next summer, 6.9 per cent of the unpainted trees were affected with new lesions as compared with 1.2 per cent of the painted.

In 1912 the Limoneira Ranch at Santa Paula, Cal., began using greater care in keeping soil away from the base of the trees. The trunks of the trees were also frequently sprayed with Bordeaux mixture and most of them painted with Bordeaux paste. The number of newly infected cases are shown in the following table:

TABLE. 1.—SHOWING PREVENTION OF GUMMOSIS BY PULLING SOIL AWAY FROM THE TRUNKS AND TREATING WITH BORDEAUX MIXTURE

	Total number of trees	Number of trees newly infected					
		1912	Per cent	1913	Per cent	1914	Per cent
Bordeaux paste	21,664	727	3.3	459	2.1	110	0.5
Bordeaux spraying	280	No record		No record		3	0.9
Controls, not sprayed	280	No record		No record		10	2.8

This decrease in three years was from 3.3 to 0.5 per cent, apparently due to the adoption of preventive measures based on a knowledge of the real nature of the disease. It is seen that the unsprayed trees showed 2.8 per cent of newly infected trees, or somewhat the same as the average for 21,664 trees in the same locality in 1912. The sprayed trees, however, showed only 0.9 per cent newly infected, or about one-third as many.

Treatment.—Even when careful attention is given to prevention, a few cases of Pythiacystis gummosis will often occur from time to time, especially with trees on susceptible stocks planted in heavy soils. The following method of treatment has been adopted as the result of much experimental work in which the cooperation of many Citrus growers has been of great assistance (Fawcett 1915). The extent to which the bark is killed through to the wood is first ascertained by scraping slightly. Then the brownish killed bark (invaded zone) is dissected out with a heavy knife cutting through to the wood about ½ inch (1.3 centimeters) beyond the invaded zone on the sides, and 1 to 2 inches (2.5 to 5 centimeters) beyond at the top and bottom in a manner similar to that shown in Fig. 24. The cuts on the two sides are usually brought together above and below, making an acute angle. No attempt is made to cut beyond the outer gummous zone, since it has been shown that this zone does not contain the invading parasite. The live bark over this zone of gummous

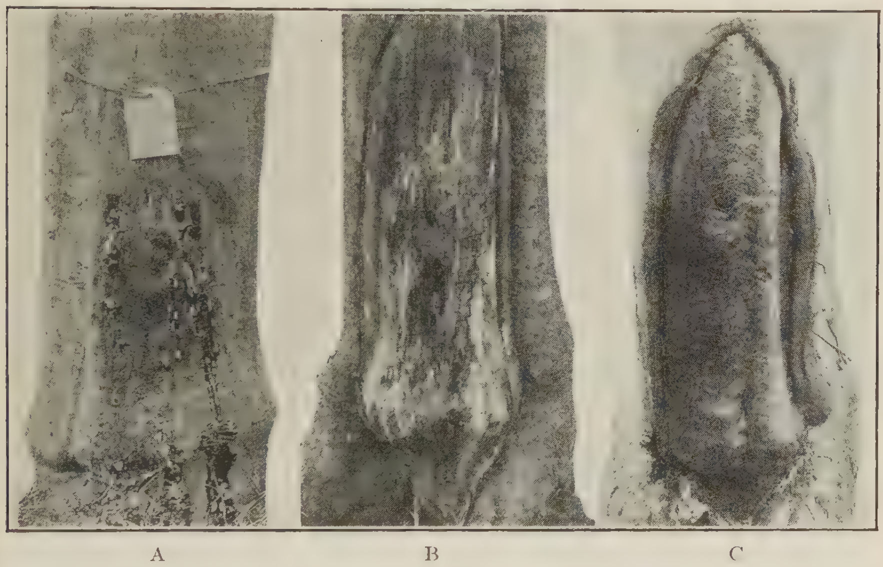

FIG. 24.—Method of cutting away diseased bark in treatment of a severe case of Pythiacystis gummosis: A, result of inoculation with a bit of diseased bark in November. Photographed in September of the following year. Invaded area 3 by 8.5 inches; B, bark cut away ready for painting with Bordeaux paste; C, same tree two years later showing growth at edges of wound and asphalt paint on the exposed wood.

influence, not yet invaded by *Pythiacystis citrophthora,* will usually recover rapidly as soon as the invaded portion has been removed and the further progress of the fungus has been stopped. These cut-out places and the entire trunk are then painted with Bordeaux paste (1 pound copper sulfate and 2 pounds rock lime to 1½ gallons of water) or some other suitable fungicide (Chap. VI).

The elimination of the tissue invaded by the causative organism is the most important feature of the treatment, the purpose of the fungicide being to prevent reinfection, or to kill the organisms in small bits of tissue left behind.

After treatment the gum usually continues to exude for some time at the edges of the cut-out areas. This is left undisturbed except for examining the edges of the cuts to ascertain whether any bark is being killed by further invasion of the fungus. The gum appears to act as a protective covering under which callous tissue is readily formed along the edges of the cuts. After these cut edges begin to heal, the exposed wood is painted with asphalt paint or other good covering (Fig. 24).

Where a large part of bark on the trunk has been killed by the rapid invasion of *Pythiacystis citrophthora* so that the trunk is girdled or nearly so, bridge grafting and inarching may often be resorted to in order to save the tree.

The advisability of this practice, in any particular instance, will depend upon the age and condition of the tree and other factors. A modification of the usual method of bridge grafting has been successful with Citrus. Instead of a shoot or branch being grafted into the bark, both above and below the injured portion, a sprout at or below the lower edge of the wound is allowed to grow. When of sufficient size, the top part is cut off, bent over and grafted into the bark above the diseased area.

Another similar method of saving or aiding an injured tree is inarching, in which one or more small seedling trees are planted close to the trunk and the top grafted into the bark above the injury (Fawcett 1923*c*; Hodgson 1924). Where quick relief is necessary and suitable sprouts cannot be stimulated, this method has proved beneficial (Fig. 25).

Example of Successful Treatment.—An example previously referred to under Contributing Conditions, of what can be done in controlling Pythiacystis gummosis when it is treated promptly and with care is furnished by a 5-acre lemon orchard at Whittier, Cal., on clay loam soil, where conditions facilitating infection obtained. About 20 per cent of the six-year-old trees became infected after a period of heavy rains following the application of green, freshly cut barley about the trunks in March, 1914.

The lesions noticed in May varied in size from those just started to lesions extending one-half to two-thirds around the circumference of the bark on the trunk. On May 25, 1914, the trees were treated by dissecting out all the brown killed bark (invaded zone) and cutting about $\frac{1}{2}$ inch beyond this invaded zone on the sides and 1 to 2 inches beyond at the top and bottom, as is shown in Fig. 25. These cut-out places and the entire trunks were painted with Bordeaux paste, and, in order to prevent further infection, the soil was pulled back from the trunk as far as the top of the first main roots.

After treatment the gum continued to exude in considerable quantities at the edges of the cut-out areas. This gum was left undisturbed except for examining the edges of the cuts to ascertain whether the bark was being further killed. The gum appeared to act as a protective covering under which callous tissue was soon seen to be forming rapidly along the edges of the cuts.

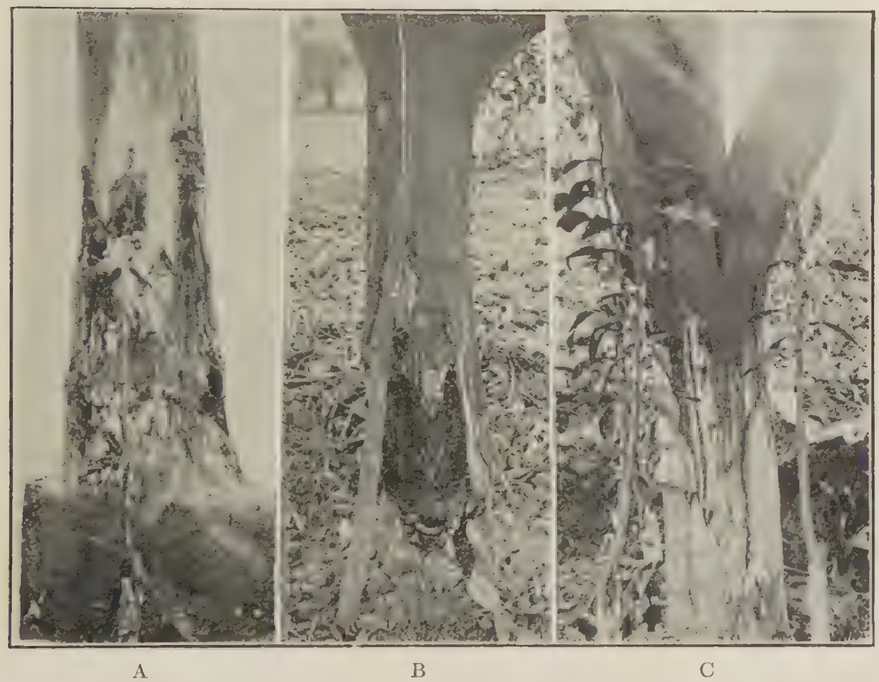

Fig. 25.—Inarching in connection with gummosis: A, showing affected tree with one-fourth inch sour orange seedling inarched across the lesion. April 1, 1916; B, same tree on Aug. 19, 1919, showing increase in inarched portion; C, valencia orange tree 20 years old, nearly girdled by Pythiacystisgummosis lesions, saved by inarching with sour orange seedlings.

In June, about one month after treatment, an inspection showed only five trees with new areas of killed bark, all of which areas were on trees previously treated. In August and September, fifteen additional areas of killed bark were found, all except two of which were on trees previously treated.

By July of the following year, a rapid healing was noted at all the cuts and no effect on the foliage could be detected. Only three new lesions, all originating below the surface of the soil, were found. Only three trees which had lost bark from areas extending over two-thirds to three-fourths their trunk circumferences were showing even a slight yellowing of the foliage, but only on branches directly above the dissected areas. By March, 1916, however, only one tree showed any appreciable effect of the removal of bark, and this was one from which about 120 square inches had been removed. The trunks of all the trees had been painted again with Bordeaux paste in the fall of 1915, and no new cases were found during the spring and summer of 1916.

Healing of Wounds Made in Treatment.—The rapidity of healing of cut-out places of various sizes in the above example is indicated by the following table. These figures were obtained by measuring the areas in two directions and estimating the number of square inches in each. While the figures are only approximate, they give a rough idea, at least, of the rate at which the different sized areas on lemon trees of this age may be expected to close up with new bark tissue.

TABLE. 2.—SHOWING RATE OF HEALING OF WOUNDS OF VARIOUS SIZES MADE IN TREATMENT OF PYTHIACYSTIS GUMMOSIS

Number of areas	Size of original areas, May, 1914, square inches	Average size of areas, June, 1916, square inches	Average size of areas, April, 1921, square inches
5	0.5	0.0	0.0
3	1.0	0.08	0.0
8	2.0	0.97	0.0
4	3.0	1.2	0.0
10	4.0	2.7	0.6
2	5.0	3.5	0.5
5	6.0	3.7	0.0
4	7.0	2.5	0.9
7	8.0	4.0	0.6
5	10.0	4.2	1.0
2	11.0	8.0	2.0
5	12.0	9.8	3.2
3	16.0	11.3	5.0
5	22.0	17.0	5.6
4	35.0	27.0	7.5
3	40.0	22.0	15.0
7	50.0	42.5	25.0
4	75.5	55.0	23.7
5	105.6	69.0	39.6
1	130.0	80.0	60.0

It will be noted that all wounds less than 3 square inches in size at time of treatment were closed, or insignificant, at the end of two years. Nearly all wounds less than 10 square inches (62.5 square centimeters) in size at time of treatment were closed in seven years. Areas larger than 10 square inches at time of treatment were reduced to about one-half to two-thirds of their original size in two years and about one-third to one-fourth their original size in seven years.

Treatments for Gummosis to Be Avoided, or Used with Care.—A treatment for wounded tree trunks, mention of which is found in very early literature, is the use of fresh cow dung applied to the surface of wounded tissue. Whatever value this practice may have for mechanical wounds when parasitic organisms do not get started in such a medium, it is certainly extremely dangerous when applied to tree trunks affected with either Pythiacystis or other types of gummosis, as ideal conditions for growth of the fungus parasites would seem to be furnished by the presence of the fresh, moist cow dung.

Another treatment which frequently results in injury to the trees is the use of neat's-foot oil. Considerable evidence has been collected to the effect that this substance has often killed considerable bark or furnished a condition favorable to the growth of the parasites. Experiments in the laboratory showed that *Pythiacystis citrophthora* grew as well on the surface of bark previously treated with neat's-foot oil as on that which had not been treated, and *Botrytis cinerea* grew much better on bark to which neat's-foot oil had been applied.

Light, penetrating oils, such as kerosene, should be used with much caution on Citrus bark. A number of cases have been observed where kerosene applied at the base of the tree trunk caused the death of the bark at and below the surface of the soil where it had not volatilized readily.

Control Methods for Pythiacystis Gummosis Summarized.—Under average conditions, this disease is prevented by keeping the soil pulled away from the base of the tree trunk until the tops of the first main roots are exposed; by keeping the soil next to the trunk from becoming excessively wet; by avoiding injuries to the bark; by painting the trunks with a fungicide, such as Bordeaux paste; and by using good sour-orange or other resistant stocks budded high for all new plantings, especially on heavy clay soils. The disease is treated, when not too far advanced, by cutting away the invaded, killed bark, but not necessarily the outer gummous zone, and painting the wound with a fungicide; by scraping away any outer layers of dead bark; by painting exposed portions of wood, after healing of the edges begins, with benzine-asphalt paint or other suitable covering; by cutting back or thinning the tops of trees severely affected; and by inarching or bridge grafting in certain cases. For details as to prevention and control the previous discussion may be consulted.

MAL DI GOMMA

Mal di gomma, also known as foot rot, and collar rot, is a gum disease very similar in its effects and even in its symptoms to Pythiacystis gummosis. The form known as mal di gomma in Florida is considered at the present time (Fawcett 1915, Stevens 1918) to be due for the most part to the fungus *Phytophthora parasitica* Dastur (*P. terrestris* Sherb.). So similar is this disease to Pythiacystis gummosis that, when occurring under the same conditions on old orange trees, the lesions cannot be readily distinguished one from the other. From the practical standpoint of the grower, they might just as well be considered one and the same disease. The prevention and treatment methods are the same for both. Since, however, the distribution and the comparative resistance of varieties are somewhat different, each will be considered separately here.

Distribution and History.—Mal di gomma or a very similar disease appears to be quite world wide in its distribution (Fig. 26). Gum diseases of this nature have been reported in practically every country in which Citrus is grown commercially, and such diseases have probably received more attention in connection with Citrus than any others. For an historical review covering gum diseases in general, of which this type was probably prominent, see page 122. Beginning with the first recorded outbreak of commercial importance in 1834 in the Azores, it was found causing trouble in the Mediterranean countries about thirty years later: in Messina in 1863; in Reggio in 1864; in Palermo and Lisbon in 1865; in Genoa in 1870; in Balearic Islands in 1871. About this same period, 1860 to 1870, it was reported in New South Wales. In the United States, mal di gomma, or related gum diseases, attracted attention in 1875 in California and in 1876 in Florida. Mal di gomma was reported in Queensland, Australia, also in 1876, and in New Zealand in 1885. It

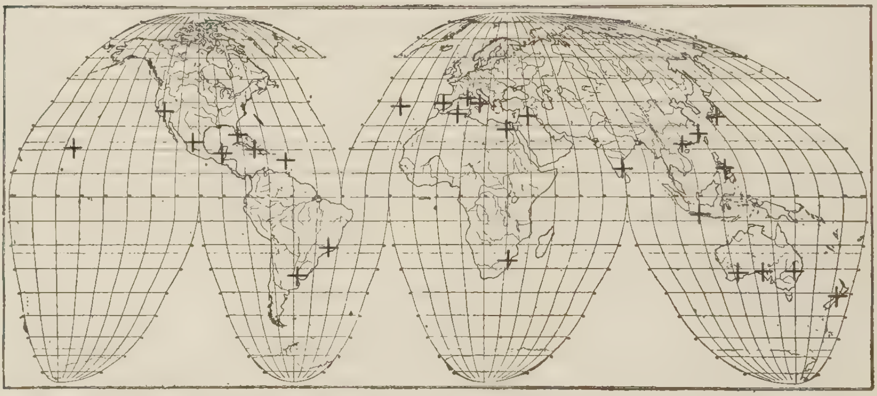

Fig. 26.—Map showing known distribution of mal di gomma and related Phytophthora gummosis diseases.

had attracted attention in South Africa by 1891. By about 1890 mal di gomma or a similar disease was probably known in nearly every country where Citrus was grown. According to Savastano (1910), the disease was so destructive about 1863 to 1870 in Sicily as to kill all the trees, and the new orchards since then have been planted almost entirely with the resistant sour-orange stock. According to Lee, it is probably the most destructive disease which occurs in Japan at the present time and is also of general occurrence in China and the Philippines. It was the first disease to attract serious attention in Florida, and, although known there since 1876, the first serious outbreak was reported in 1879 following a year of very heavy rainfall. The history of the companion disease, Pythiacystis gummosis, in California has already been given (p. 126).

Symptoms.—This type of gum disease, like the Pythiacystis gummosis, affects, for the most part, the bark on the lowest portion of the trunk and the upper portion of the highest main roots. Gum usually forms on the trunk of the tree above the soil. The inner bark, and finally the wood underneath, frequently decay and develop, especially in humid climates, an ill-smelling odor.[1] The bark dies and breaks away in patches, leaving bare, dead areas, and the disease continues to spread in all directions, upward and downward, on the main crown roots and base of trunk and laterally around the trunk. Trees thus affected usually put on temporarily a heavy crop of inferior fruit and the leaves become yellow. The external and internal symptoms in the early as well as the later stages in the formation of the lesions, especially those which occur above the soil surface, are so nearly the same as Pythiacystis gummosis that for details the reader is referred to the description of symptoms under that disease (p. 127). Briefly summarized they are.

1. Regions of bark on the trunk or roots are killed through to the wood; mineral brown to burnt umber in color at the cambium layer.

2. An outlying zone surrounding the invaded region has bark still alive and normal on the exterior but yellow ocher to chamois colored at the cambium, indicating a region of initial gum formation that extends far beyond the fungus-invaded mineral-brown region.

3. Gum, frequently in large quantities, collects in masses on the surface of the bark or on the soil below. The presence of exterior gum, however, is not a good diagnostic character, since its quantity varies much with conditions and it is readily dissolved by rains or excessive moisture and is carried away.

---

[1] This rotting of the wood, as well as the bark, and the accompanying fetid odor are believed to be due mainly to secondary organisms setting up fermentation and decay below the surface of the soil after the bark is killed by the primary organism. While gum may be formed below as well as above the surface of the soil, it is dissolved readily by moisture and is usually less conspicuous below the soil surface. This disease, under California conditions, cannot be distinguished from certain phases of brown rot gummosis except by means of culture tests for isolating the causal organisms.

Causal Agent.—The fungus which has been shown to be capable of producing lesions identical with those of mal di gomma and which has been isolated repeatedly from such lesions, especially in Florida, was

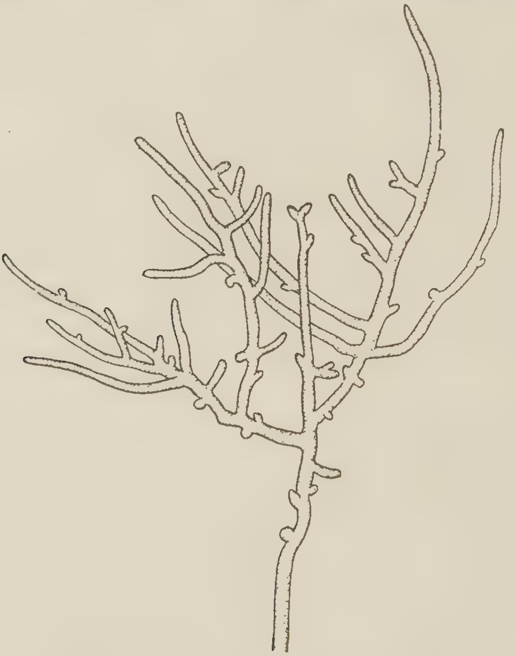

FIG. 27.—Section of mycelium of *Phytophthora parasitica* from Citrus gummosis grown in nutrient agar plus 0.5 per cent glucose. Magnified about 150 diameters. Compare with Fig. 23.

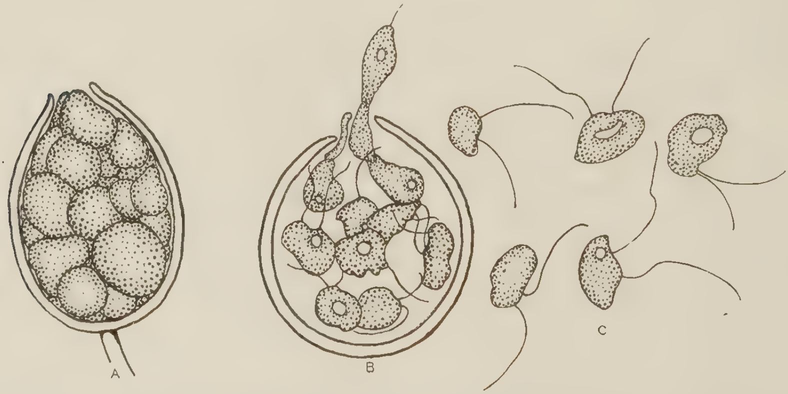

FIG. 28.—*Phytophthora parasitica* Dastur: A, sporangia with swarm spores forming, ×500; B, swarm spores being liberated through the pore in the apex of the sporangia, ×750; C, ciliated swarm spores with two cilia each by which they swim about in the films of water, ×750. Compare with Fig. 22. (*After Dastur* (1913).)

described by Sherbakoff as *Phytophthora terrestris*. It is now considered by most authors, including Sherbakoff, to be a form of the species, *P.*

parasitica Dastur. If this proves to be correct, the causal agent for mal di gomma has a wide distribution both as to host and region, as indicated by the great variety of hosts on which it has been found and the many different countries in which it has been reported, under the two names.

The fungus was first described from a form on castor-bean leaves by Dastur (1913). It has both inter- and intracellular hyphæ, 3 to 9μ in diameter. The sporophores are 100 to 300μ long with a terminal sporangium ovoid and colorless 25 to 50 by 20 to 40μ. The zoöspores (swarm spores) are 8 to 12 by 5 to 8μ. Chlamydospores are yellow and thick walled 20 to 60μ in diameter. The oögonium is 18 to 25μ with a thick, yellow wall. The oöspores vary from 15 to 20μ and are spherical and colorless. The oögonium is formed on the end of a branch that has first grown through the antheridium. Sherbakoff's (1917) measurements for the form found on the tomato are: sporangia 24 to 35 by 36 to 46μ, swarm spores 9 to 11μ in diameter, chlamydospores 30 to 40μ, oögonia 19 to 24μ, oöspores 18 to 21μ. (Figs. 27–29.)

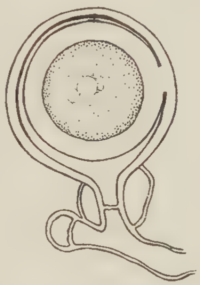

FIG. 29.—*Phytophthora parasitica* showing oogonium or perfect stage in which the thick walled oospores are developed. ×1000. (*After Dastur* (1913).)

In connection with Citrus, this fungus was first isolated from gummosis lesions at the junction of the root and trunk of an orange tree at Lindsay, Cal., in 1912 by Fawcett (1923*a*), who recognized it as somewhat different from *Pythiacystis citrophthora*, but since, on inoculation, it produced an identical type of lesion to that of similar inoculations with *P. citrophthora* it was considered at the time to be only a peculiar strain of the latter. Later in 1914, he again isolated the same form from mal di gomma lesions in Florida, Cuba and the Isle of Pines, and still considered it to be a strain of *P. citrophthora*, to which its vegetative and its imperfect spore stage have close resemblances (Fawcett 1915*b*). Stevens (1918) later made an extended survey and isolated this species in a large number of mal di gomma cases from widely separated localities representing the principal part of the Florida Citrus belt. In the meantime Sherbakoff (1917) had shown that the fungus was the cause of a rot of tomatoes in Florida. The cultures previously isolated in California, Florida and Cuba were then examined by Sherbakoff, who concluded that they were all similar to his fungus. A culture from a lemon tree sent by G. L. Fawcett from Argentina in 1916 was also determined by Sherbakoff to be similar. Later, H. S. Fawcett (1921*a*) determined that the Citrus form of *Phytophthora parasitica* (*terrestris*) had markedly different growth-temperature relations from those of *Pythiacystis citrophthora* (Fig. 30). The vegetative growth on certain culture media, the method of forming sporangia and the effect on the host when inoculated are so similar, however, as to make it seem probable that the two are related species.[1] (Compare Figs. 27–29 with 21–23.)

---

[1] See recent paper by Leonian (1925).

Dastur (1913) described *P. parasitica* as causing a disease of castor-oil plants in India and later (1916) found it attacking *Vinca rosea.* Since then, it has been found by Ashby (1920) as causing a leaf-stalk disease of coconuts in Jamaica. He has also found it on tobacco and pineapple. It has since been reported on tomatoes in England by Bewley (1923). More recently, Dufrenoy has sent a culture of Phytophthora isolated from citron trees in Corsica which is quite similar and perhaps identical with *P. parasitica.*

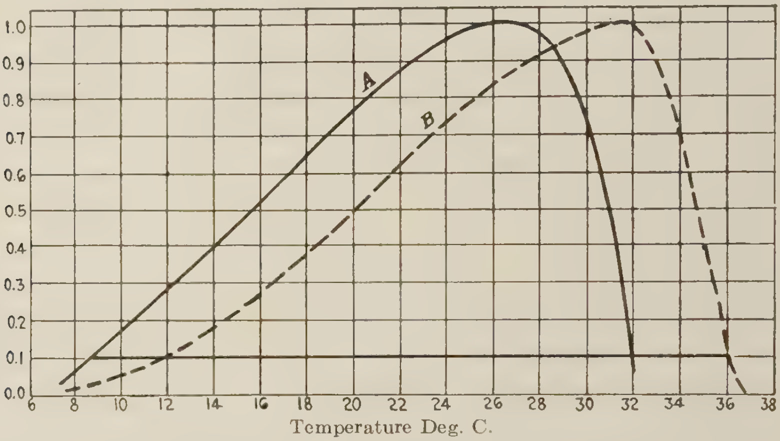

Fig. 30.—Growth-temperature graphs of *Pythiacystis citrophthora* (A) and *Phytophthora parasitica* (B) showing the respective temperature ranges of each fungus. The maximum growth was taken as unity (1.0). (*Fawcett* 1921*a.*)

Contributing Conditions.—The contributing conditions for infection by the fungus and for development of the disease are practically the same as that for Pythiacystis gummosis. Since, however, the temperature relations are somewhat different, (the mal di gomma fungus *P. parasitica* having a somewhat higher range for growth (Fig. 30) and an optimum about 7 to 9°F. (4 to 5°C.) higher) one would assume that it would thrive well in a warmer climate or under periods of higher temperatures than the Pythiacystis gummosis fungus.

It is of interest in this connection that Florida and Cuba, where *P. parasitica* has been generally found, have their rainy season in summer while California, where *Pythiacystis citrophthora* (with a lower range and lower optimum) is most commonly found, has its rainy period in winter and early spring, a time of lower temperatures. Other contributing conditions which apply equally well to this disease may be found under the discussion of Pythiacystis gummosis (p. 135).

Susceptibility of Species and Varieties.—The relative susceptibility of species and varieties to mal di gomma, as far as is known, is somewhat the same as that for Pythiacystis gummosis, except that possibly lemons are a little less susceptible to the former than to the latter (Fawcett 1923*a*, *b*.)

Hume (1911) from field observations places the relative susceptibility of species and varieties to mal di gomma in Florida from highest to lowest as follows: sweet orange, lemon, pummelo, trifoliate orange, rough lemon and sour orange. Lee's (1925) data in the Philippines showed that sweet orange, *Citrus sinensis*, was much more susceptible than pummelo, *C.*

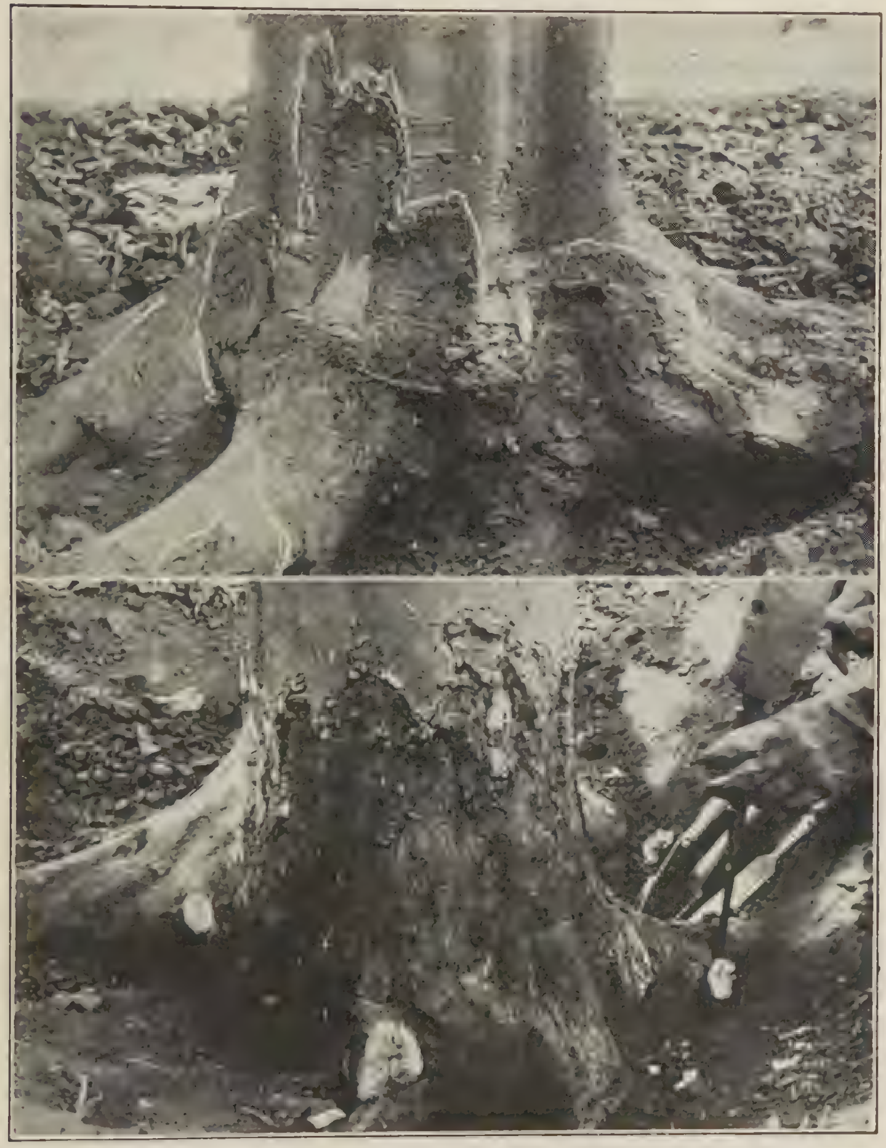

Fig. 31.—Mal di gomma or foot rot: upper, on 40-year old seedling orange tree; lower, earth dug away and affected bark and roots being removed before applying fungicide.

maxima. Limon real, a native Philippine Citrus was also quite susceptible. The calamondin orange, *C. mitis*, as well as the sour orange, *C. aurantium*, was apparently quite resistant.

The citron is also quite susceptible. According to Jones (1890), citron trees were formerly grown extensively in Sicily as hedges for dividing lines between houses, but the twenty years between 1870 and 1890 they were nearly exterminated by mal di gomma. The Mexican or West Indian lime appears also to be quite susceptible, but P. H. Rolfs writes that the Rangpur lime appears to be highly resistant or immune in Brazil where mal di gomma is generally distributed on susceptible varieties.

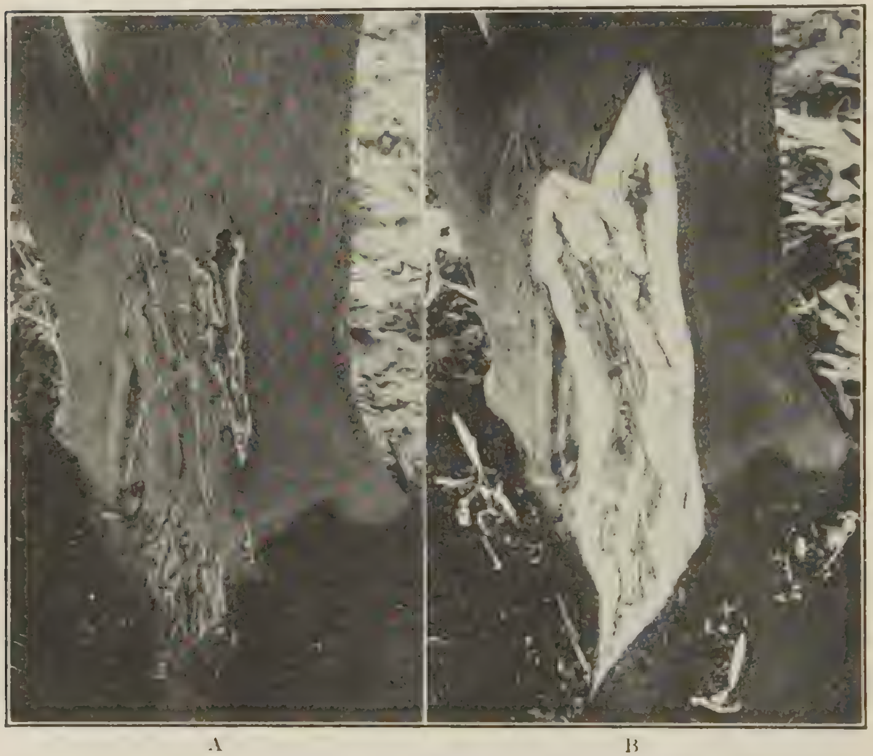
A B

FIG. 32.—Mal di gomma: A, lesions on grapefruit tree with sweet orange stocks; B, same with bark cut away to show extent of lesions. These show the characteristic tendency for the lesions to become self limited at the upper margins, and to partially heal over. (*After Lee* (1925).)

Control.—The means of preventing and treating are the same for mal di gomma as for Pythiacystis gummosis and may be found described in detail on page 139. They may be summarized briefly as follows: This disease may be prevented by pulling the soil away from the base of the trunk until the tops of the first main roots are exposed; by keeping the soil next to the trunk from becoming excessively wet; by avoiding injuries to the bark; by painting the trunks with a fungicide, such as Bordeaux paste; and by using good sour-orange or other resistant stocks budded high for all new plantings, especially on heavy clay soils.

The disease, when not too far advanced, may be treated by cutting away the invaded killed bark, but not necessarily the outer gummous zone, and painting the wound with a fungicide (p. 142); by scraping away any outer layers of dead bark; by painting exposed portions of wood, after healing of edges begins, with benzine-asphalt paint or other suitable covering; by cutting back or thinning out the tops on trees severely affected; by inarching or bridge grafting in certain cases.

SCLEROTINIA GUMMOSIS

This disease, due to *Sclerotinia libertiana*, is usually of minor importance, but occasionally has been found in California associated with the rapid dying of bark on the roots and trunks of Citrus trees growing in damp, cool locations, especially after periods of severe frost (Fawcett 1923*a*, *b*). As far as known, it has not been reported as a serious disease in any other Citrus country. The same species of fungus also attacks the twigs, blossoms and fruit (p. 310), roots (p. 103) and fruit (p. 380) under cool, damp conditions in California.

Symptoms.—The bark is at first soft, as in the case of attack by *Botrytis cinerea*. Though this fungus usually advances more rapidly than Botrytis, it is soon checked, and callus begins to form as soon as gum accumulates. Later, as the bark dries, it is left in shreds, and large black sclerotia are found within and under this bark (Fig 10). Copious gum formation on the surface usually accompanies the active stages of the disease, although external gumming is not invariably found connected with it. The most characteristic feature of Sclerotinia attack is a shredded condition of the invaded bark. It breaks up readily when pulled off into long shreds. Usually, though not always, there are present the white mycelium and flat sclerotial bodies, black on the outside but light and cheesy on the interior. The black sclerotial bodies vary in size and shape, but may be ½ inch (12 millimeters) in longest diameter. The fungus may also enter the wood, though not so readily as the bark. (For the characteristics of the fungus, see page 383 under Cottony Rot of the fruit.)

Contributing Conditions.—The conditions favoring this disease are mainly cool or moderate temperatures with a moisture favorable to the growth and development of the fungus. Injuries such as those produced by frost, sunburn, gophers, mice or tools used in cultivation contribute to the ease of entrance of the organism. When the fungus is found on the trunk or roots, observations have indicated that previous injury of the bark is usually necessary for its entrance. It has frequently been found on young trees following frost injuries, apparently advancing from frost-injured tissue into tissue not killed by frost. It has been observed on a lemon tree where all the roots had been infected, probably from injuries made in digging about them and placing vetch straw near the crown in damp, cool weather. Old seedling orange trees also have been observed with the bark on one side of the trunk killed by the fungus, which had apparently gained entrance through a small sunburned area and had advanced into the live bark for some distance. Growth of the fungus on organic matter in contact with the bark is also an important contributing condition. Fruit first rotted by the fungus in contact with the bark enables the fungus to invade the tissue. The disease has been seen starting in crotches or forks of branches where infected fruits had lodged.

Methods of Control.—The control methods to be used for this disease are nearly the same as for Botrytis gummosis (p. 188). Whenever it is possible to avoid the contributing conditions previously mentioned, such avoidance will largely prevent the occurrence of the disease. Especial care is necessary, particularly in moist weather, to avoid injuries in cultivation, picking and other orchard operations. Decaying fruit or other matter likely to contain the fungus should not be allowed to come in contact with the bark. The precautions previously mentioned for other types of gummosis, of pulling away soil that is too high against the trunk and of keeping water as much as possible away from it, are also applicable to this disease.

The principle governing the treatment of this type of gum disease after it has started is the same as that for Pythiacystis gummosis, namely, the elimination of the invaded tissue and the prevention of further progress of the disease by painting with a fungicide.

RODENT INJURY

Gophers, field mice, voles and other animals may cause severe injury to the bark on the roots and trunks of Citrus trees. With gopher injury, the bark is usually eaten off on the large roots and lower part of the trunk below ground. With injury from field mice and voles, the damage is usually near the surface of the soil and for some distance above. It is, of course, important to prevent such injury, which not only threatens the life of the tree but also causes such wounds to open up the way for root and trunk diseases, such as mal di gomma, Pythiacystis gummosis and so forth.

Control.—The control of rodents consists in trapping or poisoning the animals. It is sometimes important to see that these animals are killed off on lands adjoining that on which Citrus trees are growing. If the wounds made by these animals are discovered while fresh, they should be carefully cleaned, and if there is no danger of infection with parasitic fungi, they may be covered with hot grafting wax. If the wounds are old ones and considerable dead tissue is present, this should be cleaned away and the wound should be disinfected with mercuric chloride, mercuric cyanide, a safe carbolineum or other good fungicide (Chap. VI). Later they may be painted with grafting wax, asphalt paint or some other good covering. If the injury is large, inarching may be done to good advantage (p. 142).

FUMIGATION INJURY TO TRUNK AND ROOTS

Several different effects attending the fumigation of Citrus trees with hydrocyanic acid gas for scale insects are frequently mistaken for effects of fungus diseases. One effect of fumigation with cyanide consists in the death of a patch or strip of bark which in moist weather in California is almost always followed by the growth and rapid formation of pink spores of a species of Fusarium. The spores form in pustules or lines on the surface of the bark (Fig. 33). These dead strips vary in width from an inch to several inches up the trunk into some of the main limbs and down on the main roots following the grain of the wood. Not only the bark but some of the wood tissue is killed. The injury is usually noted some weeks after fumigation with hydrocyanic acid gas. It is thought to be due, in some cases at least, to the freezing of bark by the liquid cyanide when it is sprayed under the trees in fumigation.

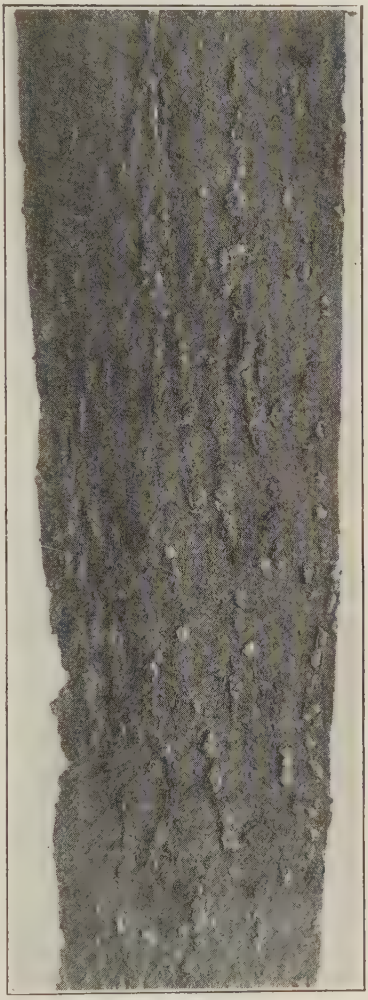

Fig. 33.—Strip of bark showing raised pustules of Fusarium spores following death from fumigation with cyanide.

Cases have also been seen where liquid cyanide, other forms of cyanide or its products have been dumped out on the soil above the roots. Roots are first killed, and then the effect is passed up the trunk and into the branches through a particular segment of the wood and bark, leaving the other part practically uninjured.

Another common effect of fumigation is to induce gum formation on the trunk near the surface of the ground. Under certain conditions of the tree, this stimulation of gum after fumigation is very pronounced

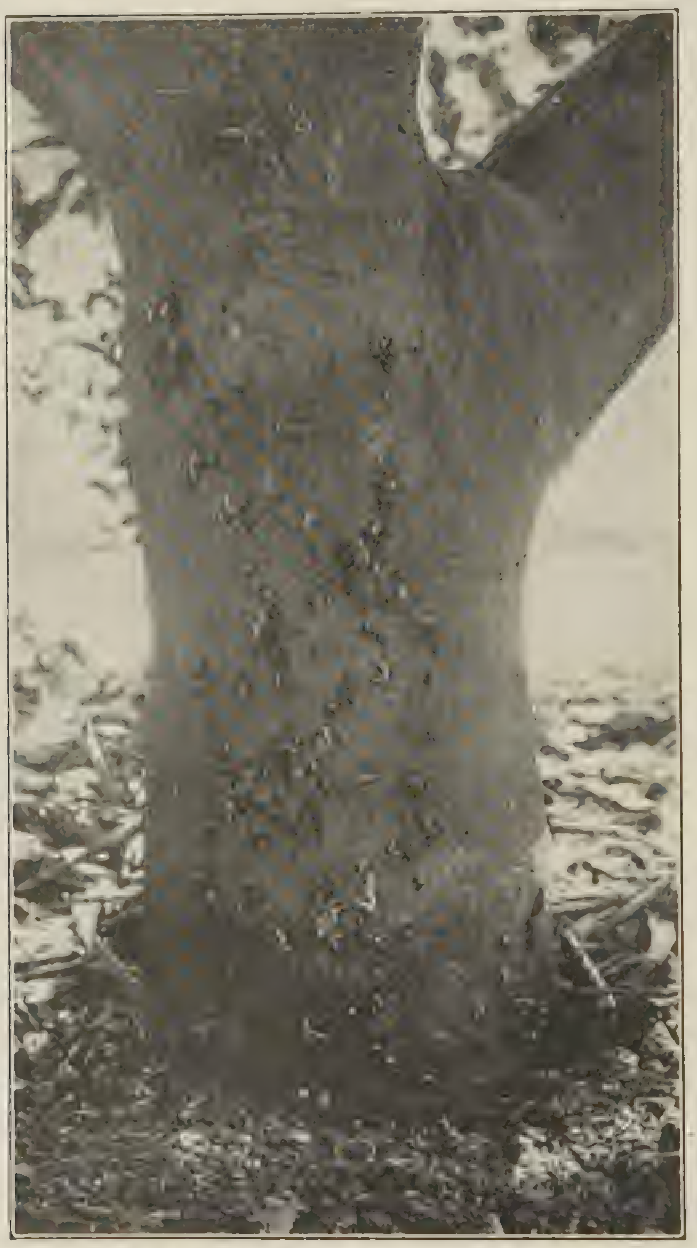

Fig. [illegible].—Extreme case of gum formation on trunk of orange tree following fumigation with cyanide. (*Photo contributed by J. T. Barrett.*)

(Fig. 34). Gum pockets form near the cambium, and gum oozes out in considerable quantities all around the base of the tree. In a few weeks this gum formation entirely ceases, the gum pockets quickly fill up again with new tissue and the only visible effect remaining is the formation of thin surface scales, just at the surface of the ground, apparently produced by the death of some of the surface bark. These thin scales are frequently mistaken for the beginning cases of psorosis, but it occurs just as readily on the sour-orange stock which is immune to psorosis as on sweet-orange stock which is susceptible.

The presence of a Bordeaux wash or spray on the tree appears sometimes to emphasize this effect. Brief discussions of fumigation injury to leaves and to fruit will be found in Chaps. XIII and XVIII.

CHAPTER X

DISEASES OF THE TRUNK AND MAIN BRANCHES

PSOROSIS

Psorosis is generally known by Citrus growers in California under the name of "scaly bark" or "scaly bark gum disease," but in Florida often under the general name of "gummosis." Psorosis should not be confused with another different disease, leprosis, known by Citrus growers in Florida as "scaly bark" or nailhead rust. The latter is distinct from psorosis and has not been found in California. It is unfortunate that the name scaly bark should have come into use in the two places for different diseases. To avoid confusion the name psorosis should be used, except in local publications, for the disease now being considered.

History and Distribution.—The disease was first described briefly by Swingle and Webber (1896) in Florida and given the name "psorosis." Other descriptions were made by Webber (1897*b*, 1902). Later, the same disease became known in California under the name "scaly bark" (Smith and Butler 1908). Since then, this disease or a similar one has been reported in nearly every important Citrus-growing section in the world; in Cuba by Cook and Horne (1908); in Mexico by Gandara (1910); in Costa Rico by Reed (1922); in Porto Rico by Stevenson (1918); in South Africa by Doidge (1924); in the Philippines, China and Japan, Guam and other Pacific Islands by Lee (1923*b*); and in Sicily by Fawcett (1925*d*). A gum disease described by Bertoni (1911, 1919) in South America appears to include psorosis. According to L. E. Toledo, it is also common in Brazil. In 1918, specimens of psorosis were identified from the Tahiti Islands, where the disease was said by Doan to be very destructive to orange trees (Fig. 35).

The sweet orange, *Citrus sinensis,* which is most commonly affected by psorosis, is believed to have originated, as its specific name implies, in China. Psorosis is of very general occurrence in China and, in fact, also in Japan and the Philippines. This widespread occurrence in the countries where the sweet orange is indigenous, by analogy with diseases of other crops which originated in the country where the host plant was indigenous, leads to the belief that psorosis originated in the Orient and has been distributed to other Citrus-growing countries, with the spread of Citrus varieties and species (Lee 1923*b*). In California, it appears to have first become common in the Riverside section and later in other parts of the state. There is also a general belief that psorosis first appeared in Florida after the freeze of 1894–1895 in orchards rebudded from bud wood sent from California.

Symptoms.—Although psorosis is generally classed as a gum disease, gum exudes only at certain seasons, or during certain phases of development of the disease, and then the gum is usually not so conspicuous a feature as it is with Pythiacystis gummosis. The slowness of the development of the disease, its inconspicuous appearance and lack of effect upon the foliage in the earlier stages, frequently prevent it from being noticed until it is far advanced.

The most conspicuous feature of psorosis is the appearance on the trunk or large limbs of irregular scales of bark $\frac{1}{4}$ to 1 inch in diameter, standing out as if pushed off from the surface (Fig. 37). It usually begins with a very small area, in which only a thin outer layer of bark dies, hardens and is raised from the surface, leaving a layer of bark underneath still alive. This first area slowly enlarges from year to year until finally it encircles the trunk or limb. Often a number of small areas begin at the same time and thus cover the surface more rapidly. Some areas may begin as a collection of small pustules, under which there are brown specks in the bark. Later the deeper layers of bark and even the wood may be affected. Gum may exude as the disease advances, but gum is not a necessary accompaniment of the disease, and its presence and amount depend on growth conditions, season of the year, etc.

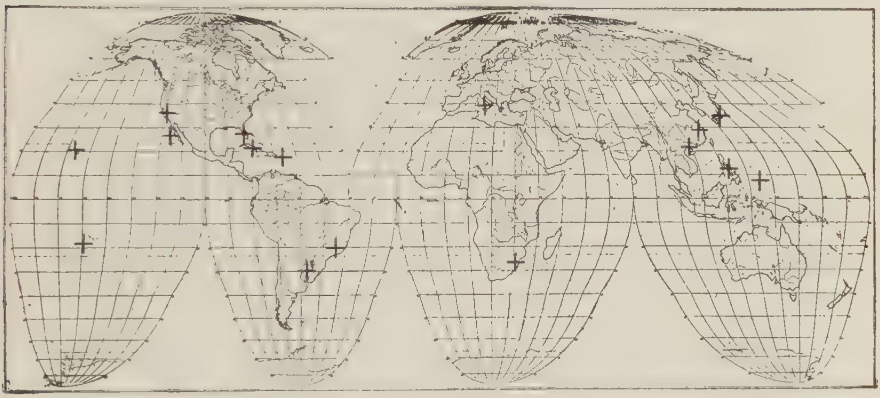

FIG. 35.—Map showing the known distribution of Psorosis.

Stages in the Development of Psorosis.—Trees affected with psorosis may be in all stages from those showing no signs of decline, on which it is just beginning (or on which it may have been present for several years), to those that show severe effects of its presence on which it has usually been present for many years (five to fifteen years in many cases).

In order to have some convenient means of referring to different stages, the gradual progress of psorosis will here be described in three arbitrary stages.

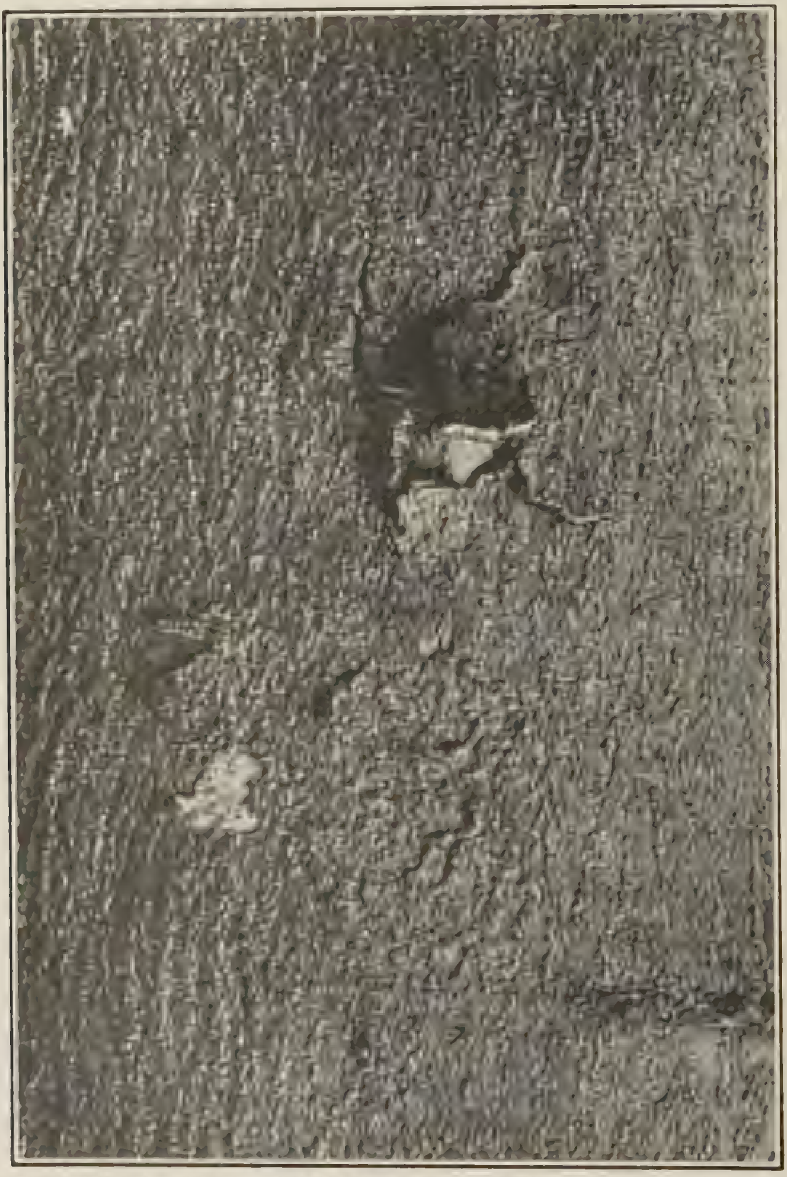

FIG. 36.—Small lesions of psorosis in the first stage on bark of sweet-orange tree showing the first formation of scales.

First Stage.—The first visible evidence of psorosis is usually the pushing off one or more dry hard scales or flakes of outer dead bark (Fig. 36).

Another evidence may be an area of bark showing a roughened condition due to a number of small blisters or "pimples" on or in the surface. Individual pimples or pustules are 1 to 3 millimeters in diameter. These may result in very minute flakes or dry scales later. The two manifestations may go hand in hand or the rough pimply appearance may precede the "scaly-bark" appearance. A slight scraping of the exterior will often show a yellowish-green, Ridgway's (1912) citron green in place of the normal green, with a wood-brown discoloration at the base of these pustules in the outer bark. It usually requires close inspection of the bark to detect the very first evidences, as they are easily overlooked or mistaken for slight bark injuries. At the very beginning, only an outer layer of bark appears to be injured or changed, an inner layer next to the cambium being still alive, active and free from discoloration, except frequently a slight greenish appearance. Later internal gum formation begins near the cambium region. The scales or flakes are irregular in outline and vary in size and thickness, but are usually from about 1/12 to 1/8 inch (2 to 3 millimeters). They may be chestnut brown or sorghum brown on the exterior. They remain attached to the surface of the bark by one end and extend outward from the surface at various angles. Underneath these freshly formed scales the surface of the remaining bark is light tan, light buff or olive-buff colored, irregular and rough. A cross-section of the affected bark shows it to be thinner at first than the healthy bark, but later it may become thicker than the healthy bark due to greater growth activity at these affected places. A yellowish discoloration may appear, due to the development of gum within the tissue. Gum pockets near the cambium region or between the wood layers beyond the cambium may sometimes appear fairly early in the development, but these do not, as a rule, appear until the disease has been present for some time. Gum may appear on the surface, especially during the active growing period of the tree.

A study of a large number of these first beginning stages leads to the conclusion that the disease usually progresses at first from the outside bark surface inward, and not from the inside outward as might, naturally be inferred from an examination of later stages only. In this first stage, the bark area affected may be from 1 to 4 or more inches in diameter and may not cover more than one-fourth the circumference of the trunk. There may be only one area at first, or a number of these small areas may appear simultaneously. Individual exceptions may, of course, be found to these general statements. A description of only the average first stage of the disease has been attempted.

Second Stage.—A further development of the first stage until the disease covers more than one-third the diameter of a trunk or has completely encircled the trunk or large limb, but has not yet seriously injured the wood underneath, may be for convenience considered the second

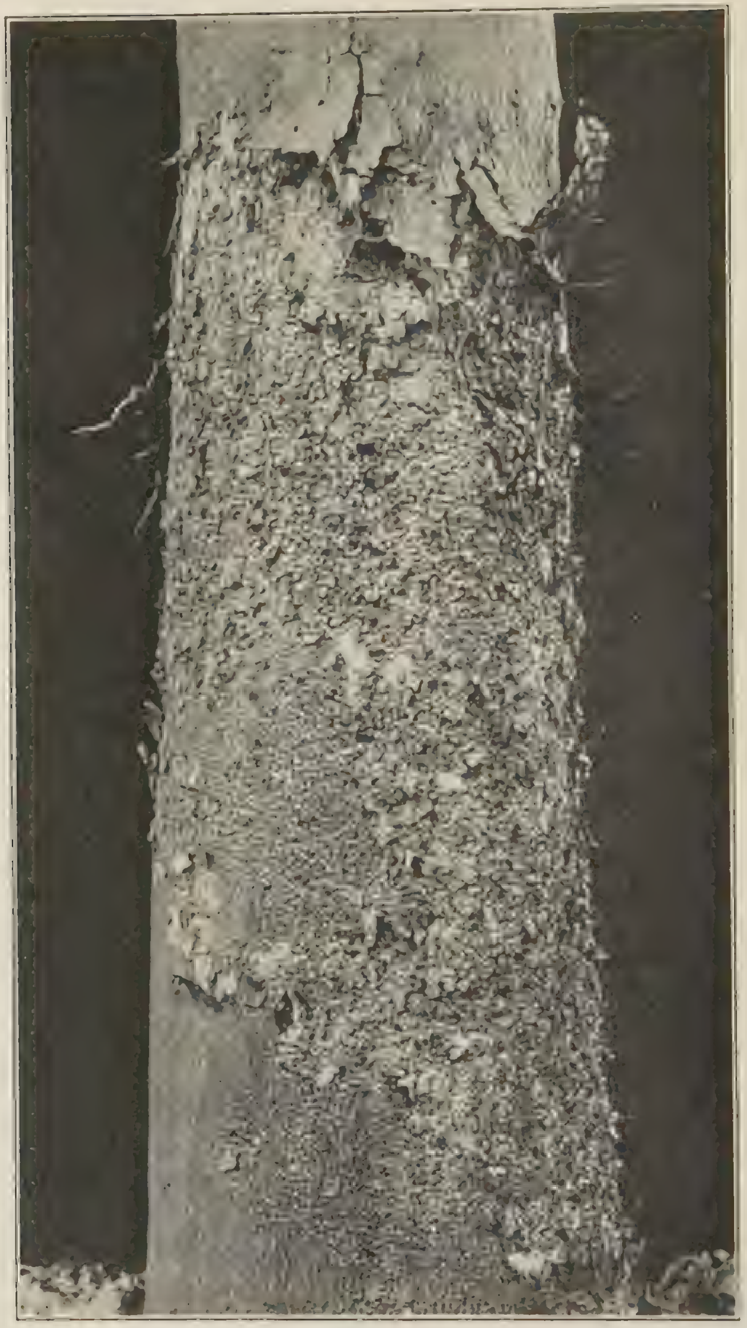

FIG. 37.—Trunk of orange tree affected with psorosis approaching the third stage.

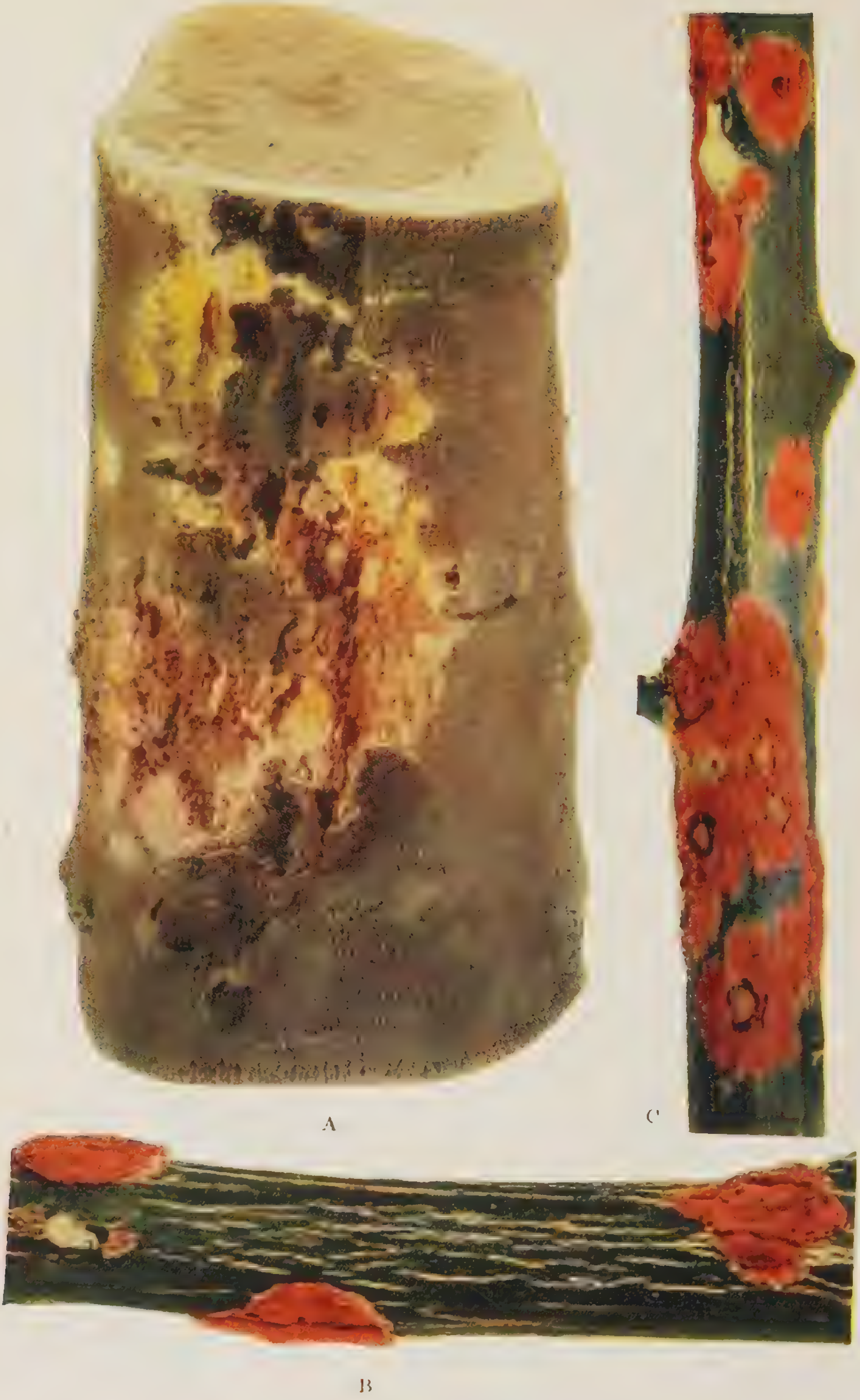

FIG. 38.—Psorosis and Leprosis. A, Psorosis (California scaly bark) on section of orange trunk showing scaling of outer bark and staining of interior wood, about one-third natural size. B and C, Leprosis (nailhead rust or Florida scaly bark) on twigs, magnified about one and one-half times.

(*Facing page* 163)

stage (Fig. 37). The affected portion often presents, at this stage, a roughened surface. Fresh scaling of the bark on the advancing edges continues and exudation of gum takes place at certain seasons of the year, but ceases at other times. Bumps or hypertrophies 1/12 to 1/8 inch (2 to 3 millimeters) high and 1/8 to 1/4 inch (3 to 6 millimeters) in diameter frequently form as the lesions advance. A cross-section of the branch or trunk at this stage may not show any definite brown stain of the wood, but rings of gummy deposits will be found between layers of wood corresponding to years or seasons, with normal wood cylinders between them. The advance of the disease appears to be within the outermost layers of bark. Scraping lightly the margins beyond the scaly area reveals a fawn to vinaceous-fawn discoloration of the outer bark surface, which indicates the location of the next flake or scale to be formed. Scraping sometimes reveals brown rings 1½ to 2 inches in diameter and perhaps 1/4 inch wide in the outer bark at this or an earlier stage.

Third Stage.—A condition which may be called the third stage does not usually develop until the disease has been present for a number of years. The time varies, but is often five or more years after the first visible beginning of the disease. The wood now begins to be seriously affected. There is a drab discoloration (at first slight) in the wood just under the affected parts (Fig. 38). This increases in extent till a large part of the wood may eventually become dark colored and may emit a foul odor when cut into.

When first cut into, this may be drab gray or cinnamon drab with vinaceous-brown or Sanford-brown lines at the margins. In bad cases on limbs, the color of salmon to rufus has been found along with an odor of smoked herring. On drying, the stain may be vinaceous fawn to army brown. This staining of the wood usually progresses in an irregular fashion not necessarily following the grain of the wood, although its progress is usually greater with the grain than at right angles to it. Almost the entire interior, with the exception of a narrow layer of wood just beneath the cambium, may in certain cases become stained in this way but remains firm and hard, unless wood-decay fungi get in secondarily. Decay of the wood may then set in, and the strips of bark heretofore alive may begin to die also. The top of the tree, at this stage, usually shows a stunted appearance. The leaves become small, yellow and few in number. Twigs die back, and the new growth is small in amount. One or two limbs only may be so affected or the entire tree may show serious effects.

Manner of Development and Probable Cause of Psorosis.—One of the difficulties presented in the investigation of the cause of psorosis has been the extreme slowness with which the disease develops in its incipient stages. In certain cases, it has been possible to transmit the disease to sound trees by inoculations with bits of tissue from diseased lesions, but most of the attempts have failed. In one of the successful cases, about two years elapsed after the diseased tissue was placed in a wound in sound bark before the disease was visible.

It is now believed that a slow-growing organism of some kind is the causal agent in the initial development of psorosis. From first-stage lesions, many kinds of organisms have, in past years, been isolated and tried out, but none have reproduced the disease. More recently another organism has been isolated from very early stages, which may be a factor in its initiation and development. There has not been time, however, to prove its real relationship to the disease.

As examples of the slowness with which the disease often develops, the following cases may be mentioned. At Riverside, Cal., two incipient lesions not yet gumming and each about 1 inch in diameter were outlined on a Valencia orange tree twelve years old. These lesions had progressed only ¼ inch beyond the original mark in two and one-half years. A slightly larger area on another tree, which was 1½ inches in diameter when first observed, became only 4 inches in diameter in three and one-half years. These areas were so small and inconspicuous when outlined that they would not have been noted at all at that stage by the average grower.

After the lesions become larger, however, they develop somewhat more rapidly. The following example represents a rather rapidly developing lesion. An area on a trunk of a twelve-year-old Valencia orange tree was 3 by 7 inches when marked; six months later, it was 8 by 12 inches; after nine months, 10 by 15 inches; after two years, 12 by 16 inches (with much gumming); and after three and one-half years, 14 by 17 inches. While this increase from 3 by 7 inches to 14 by 17 inches seems considerable in itself, it represents an average of only about 1½ inches of advance per year in any one direction. The lesion was probably three to four years old when first measured.

The visible advance of the disease depends greatly upon the season of the year. In the majority of cases it seems to be most active during the growing season and especially in summer and early fall, and to be quiescent during the winter and early spring. This great show of activity in the summer and fall is due in part to the breaking away of scales of bark, probably brought about not only by drying of the outer bark that has previously died, but also by the increase in growth of the inner live bark beneath. Gum formation and exudation also take place at this season, giving further indication of activity. Most of the advance for the year, however, appears to be finished when the gum formation is at its maximum. The gum appears to be the result and not the cause of the drying and death of the outer bark. The gum probably tends to hinder more than to aid the advance of the disease at this time.

Contributing Conditions.—As to the conditions favoring the disease, nothing very definite can be stated when all the Citrus sections are considered. Extreme irregularity in moisture conditions in the soil has been thought in the past to be a contributing condition (Smith and Butler 1908), and there appears to be some observational evidence that the disease is more prevalent on sandy or loose gravelly soils than on heavier clay soils (just the opposite to the conditions favoring Pythiacystis gummosis). It is not, however, confined to such soils. Some of the worst cases may sometimes be found on the heaviest types of soil, and even in well-cared-for orchards. A bad root system may also indirectly favor its development, and yet many bad cases have been observed where the root system appeared to be perfect when the tree was dug out. In general, it may be stated that any condition unfavorable to the best growth of the tree will probably enable the disease to develop more rapidly after it has once started. For this reason, the trees should have the best care possible to enable them to resist the inroads of the disease.

Observations have indicated that wounds or injuries of various kinds may contribute to the beginning of the disease. The lesions have been seen starting in slight injuries made by the saw in pruning trees. They have also been noted as starting around small holes in the bark made by sapsuckers or woodpeckers. They have also been noted as sometimes especially severe in trees that have been top worked after they were of considerable age.

The age of bark appears also to be a contributing condition. As a rule, psorosis does not appear until trees are eight to ten years of age, and seldom on limbs until the bark has been formed for four to six or more years. Young bark for some reason appears to be resistant to the effects of the disease. This may be the reason why the scraping method is so successful in preventing its advance. Many cases have been observed in which scraping or cutting the bark on an old lesion would appear to prevent any further development of the disease for a period of three to four years, after which the renewed bark over the old lesion would again show signs of activity.

Susceptibility of Species and Varieties. The sweet orange (*Citrus sinensis*) is probably the most susceptible species. In California, the Valencia, Navel, seedling oranges and other sweet-orange varieties are susceptible, but the Valencia appears to be one of the most severely affected. Grapefruit (*C. maxima*) is also affected usually in a less degree and tangerines (*C. nobilis* var. *deliciosa*) are affected frequently but appear to be only moderately susceptible. Sour oranges (*C. aurantium*), lemons (*C. limonia*) and many other species appear to be immune or highly resistant.

Experiments in Treatment.—Various methods of cutting, scraping and slitting the bark have been compared with no cutting or scraping. Comparisons have also been made of the application of a considerable number of substances as fungicides or coverings.

A method of scraping the outer bark to depths varying according to circumstances, to be described later, has been found effective. Scraping has been found to be much more important than the use of any kind of fungicide or disinfectant alone. Slitting has proved of little or no value in these experiments. These experiments have also shown the advisability of scraping not only the area visibly affected, but also beyond the area to a distance of from 6 to 8 inches to head off the advance of the disease in bark not yet visibly affected. The spread of a lesion in its early stages appears to take place within the outermost layers of bark. This accounts for the beneficial results of light scraping beyond the visible edge of the lesions (Fig. 39).

A large number of disinfectants and coverings were tested with and without scraping or other method of cutting the bark. For comparison, in each case, similar areas on the same or different trees were left without the application of the disinfectant. Almost without exception, the diseased trees on which the bark was carefully scraped showed the best recovery. The disinfectant applied seemed to have little effect. Lesions of the same kind not scraped continued to develop in size at the same rate, whether painted or unpainted with the various disinfectants (Fawcett 1923*b*).

The results of a cooperative experiment carefully conducted under commercial conditions by M. B. Rounds (1922), as well as our own experiments, indicated that the particular fungicide to be applied was of less importance than the manner of scraping or treating the bark. None of the trees scraped alone showed any advance of the disease, while 65 per cent of those slit alone, and approximatey 80 per cent of those not scraped or slit, showed an advance in the disease a year after treatment. The stage of the disease largely determines how each tree should be handled. For this reason, a method of treatment adapted to all cases cannot be stated in a few words. Each tree affected presents an individual problem. Like tuberculosis in the human species, psorosis on Citrus is a slow and persistent disease, much more easily handled at the very beginning than after the disease becomes well established. Just as the former disease may be present in the human body for a long time before any outward deterioration is noticed, so psorosis may be present on the trunk for years before any effect upon the foliage or fruit may be detected.[1]

---

[1] A method of peeling or stripping off the entire bark that is affected with psorosis is being used by growers to a limited extent in one locality in California. It consists in cutting through the bark a little distance beyond the limits of the diseased areas during the growing season, when the bark slips readily, and pulling off the bark. Paper is then tied over the exposed areas and the cambium encouraged to rebuild a new bark. In some cases, entire branches and trunks have been girdled in this way and appear to be forming new bark. To what extent a method of this kind will prove valuable and be sufficiently free from danger must be determined by experience.

Control.—The trunk and large limbs of all trees in an orchard should be inspected once or twice each year in order to detect the disease in as early a stage as possible. This tree-to-tree inspection of all trees is of the greatest importance, since the disease exerts no visible effect upon the foliage or growth of the tree until it has been present for a long time, usually not until the third stage is reached. Moreover, the disease may be easily cured in its early stages but is more difficult of control and frequently beyond permanent cure when the tree begins to show serious effect in the foliage.

Prevention.—Little is known definitely regarding prevention, but there is reason to believe that the avoidance of injuries to the bark and the disinfection of tools used for diseased trees before they are employed in pruning sound trees will help to prevent its spread. The presence of a fungicide upon the surface of the trunk and large limbs will also probably help to prevent infection.

The use of trees with vigorous types of sour-orange or other immune varieties as stocks for the roots and trunks of all new plantings would, of course, immunize such parts; consequently, the tops would be the only part of such trees that would be subject to the disease; these, when affected could be renewed more easily than the trunk.

Treatment.—How a tree affected with psorosis should be treated is not a simple question to answer, since the treatment depends so largely on the stage to which the disease has already progressed. Certain suggestions, however, will be made here, it being understood that these apply to typical conditions and that they may need modification when applied to any particular case.

First-stage Procedure.—At the very beginning only an outer layer of bark appears to be injured or changed, an inner layer next to the cambium being still alive and active and often free from discoloration, except that it frequently presents a slight greenish appearance. Later, a yellowish discoloration may appear, due to the development of gum within the tissue. When these beginning areas are small (Fig. 36) and do not cover more than one-fourth of the circumference, the affected bark may be scraped rather deeply and the surrounding unaffected bark scraped less deeply for a distance of 4 to 6 inches above and below, and 3 to 4 inches laterally beyond the margin of the affected areas. A good safe disinfectant is then applied. Some of these are mentioned under the third-stage procedure.

Second-stage Procedure.—When the disease has progressed further, so as to cover more than about one-third of the circumference of the entire bark on the trunk, but has not yet seriously injured the wood, it may for convenience be considered to be in the second stage. At this stage, the affected portion often presents a roughened surface (Figs. 37, 39). Fresh scaling of the bark on the advancing edges continues, and exudation of gum takes place at certain seasons of the year.

In such cases the cure is more uncertain, but the disease may be checked and frequently cured by care in scraping. Particular attention should be given to the advancing edges. The affected surface may then be treated with a disinfectant as previously mentioned. Six months or a year later these should be examined again, scraping only where the disease is still active or where it has previously been overlooked. The progress of the disease is so slow that usually it is difficult to tell within less than a year or more whether it has progressed or not. Recent

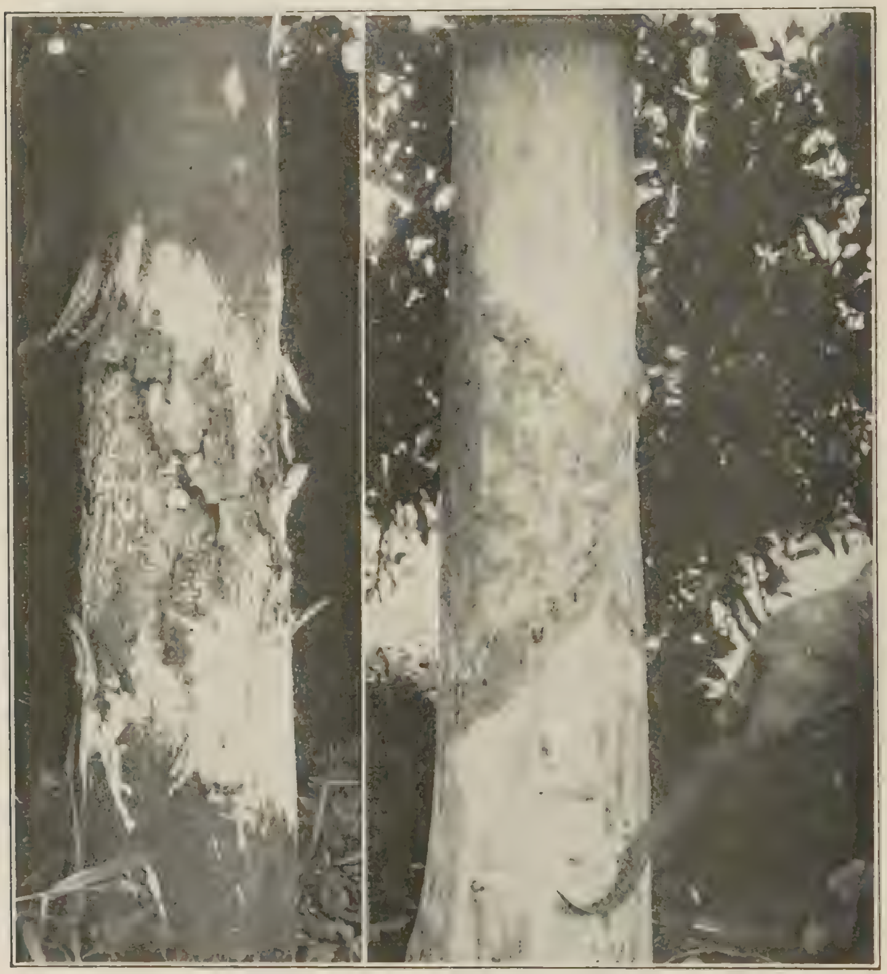

Fig. 39.—Psorosis on orange trunk: A, showing lesion in the second stage with formation of large scales of bark. The white color on the trunk is due to lime that had been used by a grower in an unsuccessful attempt to treat the lesion; B, same tree after the bark had been scraped. A little deeper scraping than is shown here should probably be given the margin of the lesion for ideal treatment.

experience appears to show that at least three years is required to determine definitely whether a particular area has been permanently cured. It is therefore suggested that, in case of psorosis, judgment be withheld regarding the permanent efficiency of any new method of treatment until three or four years have elapsed (Fig. 40).

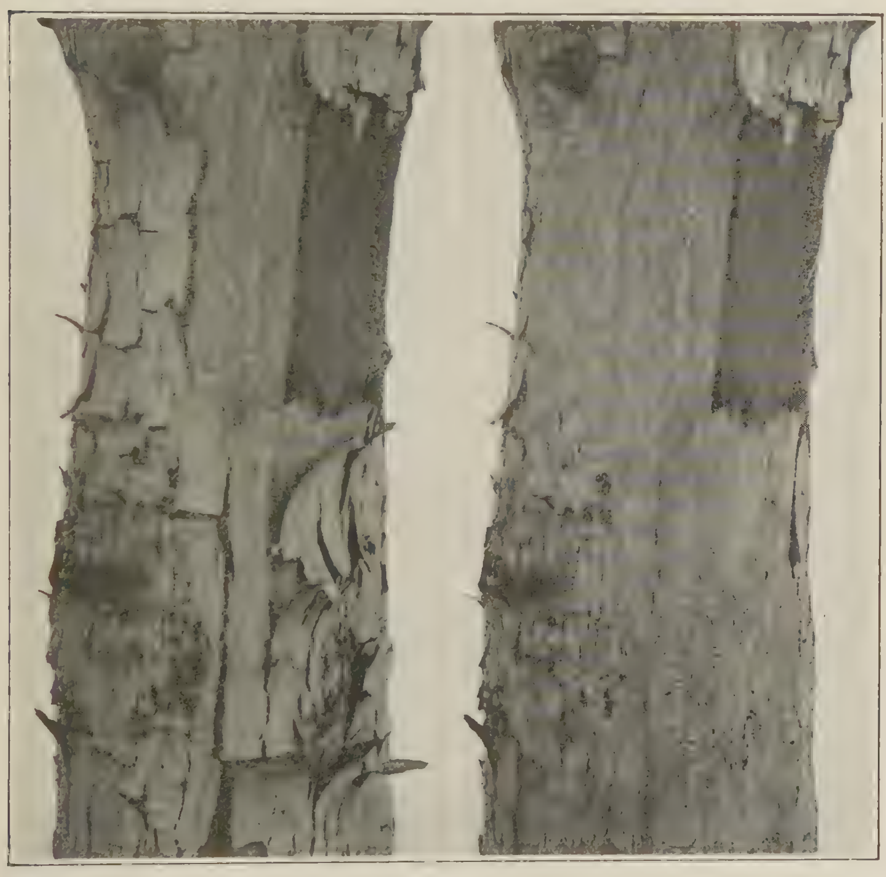

Fig. 40.—Orange trunk previously scraped in treatment of psorosis showing manner in which a thin layer of dry bark peels off after treatment: A, as seen about 9 months after scraping; B, same with part of the thin scales removed. (*Photo by W. R. Schoonover.*)

Third-stage Procedure. Where the disease has been present for a number of years (eight to ten or more) or until a greater part of the bark of the trunk is affected and the wood underneath is killed and beginning to decay, there is little hope for a permanent recovery. A tree of this kind, however, sometimes remains surprisingly productive for a number of years, so that it becomes a question whether to replace it at once or to treat it superficially with the idea of checking the disease, preventing possible spread to other trees and taking it out later after it ceases to become profitable. If only a part of the branches show the disease in the second and third stages, these branches may be cut out entirely, and the remaining part of the tree frequently inspected and treated for further outbreaks. If the wood is just beginning to be discolored and killed, this portion may be chiseled out, disinfected and benzine-asphalt paint, white lead or other good wood-protecting covering applied to the exposed surfaces. A severe cutting back of a badly affected tree may be helpful. If the trunk is too badly decayed and the entire tree appears stunted and unproductive, the tree should be dug out.

Season of the Year.—Where there is much frost hazard, or hot drying winds, bark scraped too late in the fall or during the winter months is likely to be killed by low temperatures or by desiccating winds. Experiments under California conditions indicate that bark treated in the late spring and summer months recovers most rapidly.

Fungicides.—As was previously stated, the kind of fungicide employed appeared to be of minor importance in certain of our experiments. Some kind should be applied, however, to the scraped areas, as a matter of precaution against infection, especially in moist localities or in moist, cool weather. Except for the slight danger to the foliage when followed by fumigation, Bordeaux paste has usually been satisfactory. Other substances of good fungicidal value are some of the high-boiling coal-tar products, such as "Arrow" carbolineum, "Avenarius" carbolineum or products of a similar constitution (see caution, p. 60, Chap. VI). Still other disinfectants that have been used with good results are mercuric chloride, $\frac{1}{15}$ ounce to a quart (2 grams to 1000 cubic centimeters) of a watery liquid (the liquid being one-fourth denatured alcohol); mercuric cyanide dissolved in the same proportions or a mixture of the last two solutions; liquor cresolis compositus U. S. P. (emulsified cresol, 10 per cent in water); and potassium permanganate, $\frac{1}{3}$ ounce to a quart (10 grams to 1000 cubic centimeters) of water. Bordeaux wash may be used of about 10-10-50 formula. It is not necessary to use the Bordeaux so strong as first suggested by Fawcett (1913*b*) (see formulae in Chap. VI).

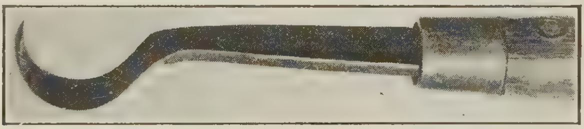

Fig. 41.—Tool for scraping the bark in the treatment of psorosis or other bark diseases. It is also suitable for gouging out small diseased areas on or in the bark.

Tools.—Several kinds of scrapers are used for scraping the bark. The type in common use in California is shown in Fig. 41. It is made of spring steel and consists of a curved blade sharpened on both edges and at its end and set in a wooden handle. The handle is about $7\frac{1}{2}$

inches long and 1½ inches in diameter, and the steel part containing the curved blade is about 5½ inches long.

BARK ROT

Bark rot is a disease upon which there has been little research, and therefore, very little is known regarding it aside from its appearance, hosts affected and seriousness.

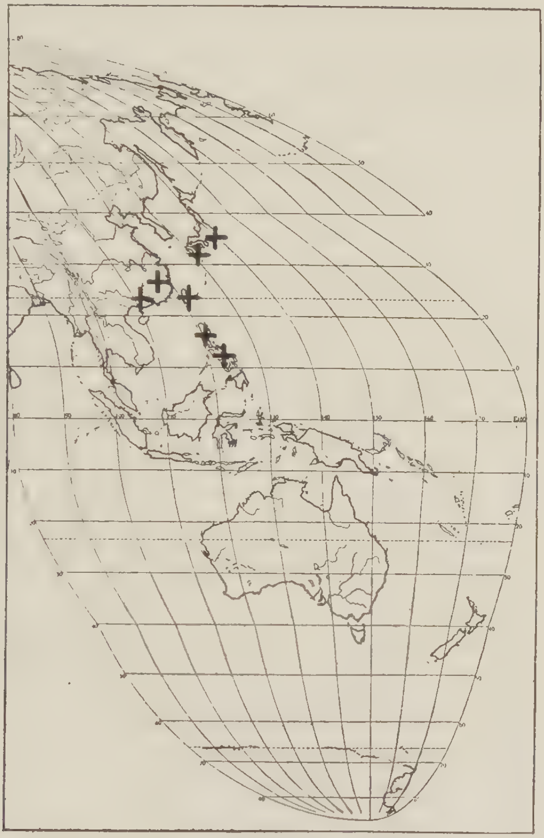

FIG. 42.—Map showing known distribution of bark rot.

It has not yet been reported from the western hemisphere, and for that reason every effort should be expended to maintain its entire exclusion from western countries. It is not yet entirely distributed in the eastern hemisphere, for, although it is very general in China, Japan and the Philippines, it does not occur in Java nor has it been reported from Australia (Fig 42).

Susceptibility of Citrus Species.—It is probable that bark rot would not be serious either in California or Florida, since it affects the tangerine and true mandarin oranges, *Citrus nobilis* var. *deliciosa*, most seriously and the Satsuma oranges, *C. deliciosa* var. *unshiu*, possibly but slightly less. Since Satsumas are more widely grown in the Gulf states, it would be expected to cause material injuries there. It might also be very serious if it broke out in Java where mandarin oranges are commonly grown.

Bark rot also affects to a slight extent the calamondin, *C. mitis*, and the cabuyao trees, *C. hystrix*, and questionable cases have been seen on lemon trees, *C. limonia*. It has not been observed to affect the sweet orange, *C. sinensis*, the grapefruits or pummelos, *C. maxima*, or the limes, *C. aurantifolia*; trees of all of these species are commonly grown in affected areas, so that they have been freely exposed to infection.

This, like psorosis, is one of the diseases to which old trees are apparently more susceptible than young trees. Young orchard trees have never been observed to be affected until three years after planting, but older trees under the same orchard conditions are frequently severely injured.

In China, where mandarin oranges are the principal Citrus crop, bark rot is probably the most destructive of any of the Citrus diseases. Not only large branches but whole trees are killed by this disease. Although newly planted orchards show none of the trouble, 50 per cent or more of the trees when six or seven years old will show infection, and by the time the orchard is ten or twelve years old only a few isolated trees of the original stand remain. According to Lee (1923*b*), "An aspect of its seriousness . . . may be gained by the statement that not a single mandarin orange tree was observed in the Canton delta over fifteen years old."

In Japan where the Satsumas, which are not quite so susceptible, are the principal crop, the disease is not so destructive, but nevertheless it causes material losses. Next to mal di gomma and scab, it is the most destructive disease of Satsumas in Japan.

Symptoms.—The most obvious symptom is a white foam or froth exuding from longitudinal cracks in the bark as shown in Fig. 43. This white exudate is not, as might be hastily concluded, a bacterial ooze, but is found to be a mass of yeast cells and mycelia of fungi. These organisms apparently causing this white ooze are believed to be secondary agents.

Closer examination shows that the disease is primarily a solution of the soft, actively functioning cells of the bark. The bark cracks as a result of this process, as shown in Fig. 45, and insects attracted by the products of this solution obtain entrance through the cracks in the bark. The white exudate is apparently the result of these secondary agents. The internal nature of the lesion is shown in Fig. 44, where the bark surrounding one of these cracks is cut away. Following the initial cracking of the bark, the tissues are killed both longitudinally and laterally, resulting in a final killing of the affected limb. The lesions of bark rot are not confined to the trunk and larger limbs, but extend well up into the tree and have been observed upon limbs as small as $\frac{3}{5}$ inch (15 millimeters) in diameter.

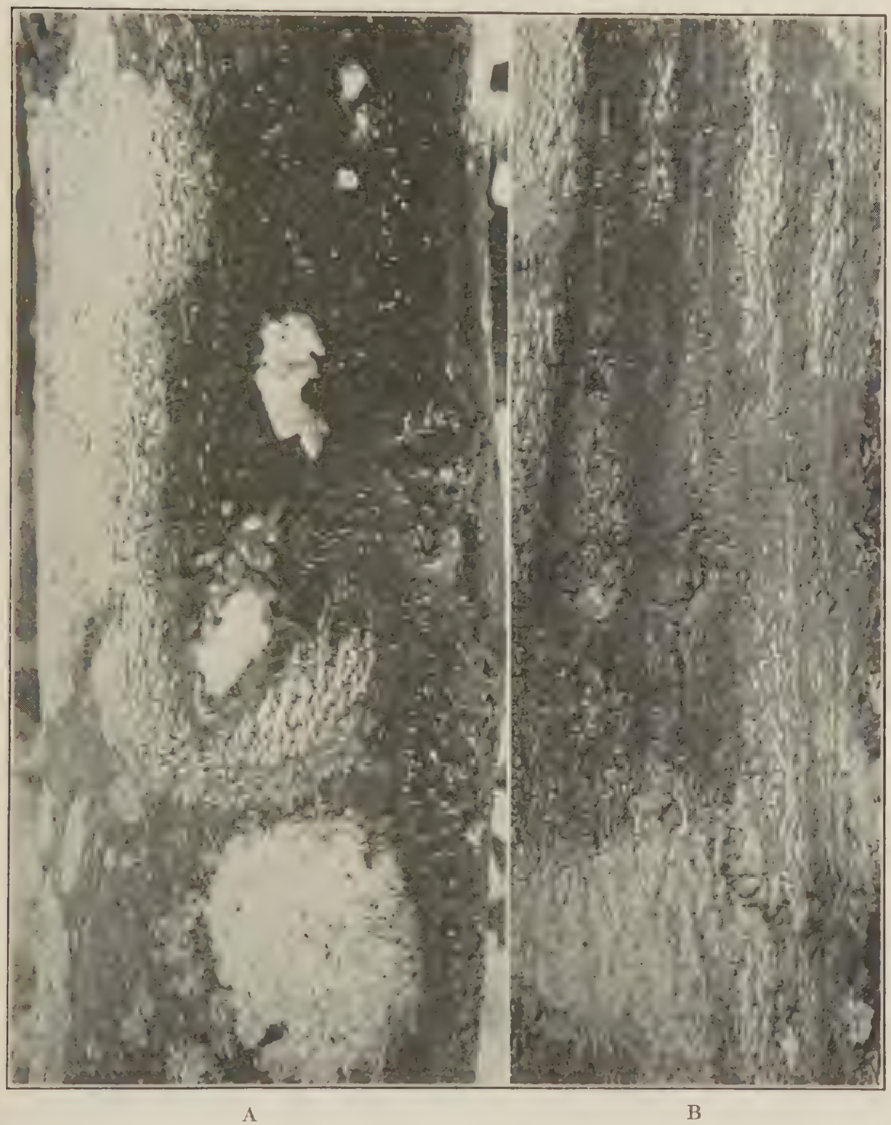

Fig. 43.—Bark rot of Citrus. A, showing the white ooze which is one of the first and most noticeable indications of a bark rot lesions; B, cracks in the bark from which white ooze has emanated and run down the bark of the tree.

Direct injury results from the gradual increase of these lesions and subsequent dying of the tissues, finally resulting in a complete girdling of the limb or trunk. Usually, however, long before complete girdling has taken place, the lesions have afforded means of entrance for insect borers and similar destructive agents, and death is apparently hastened. The disease progresses slowly in comparison with other Citrus diseases, but the results are none the less serious.

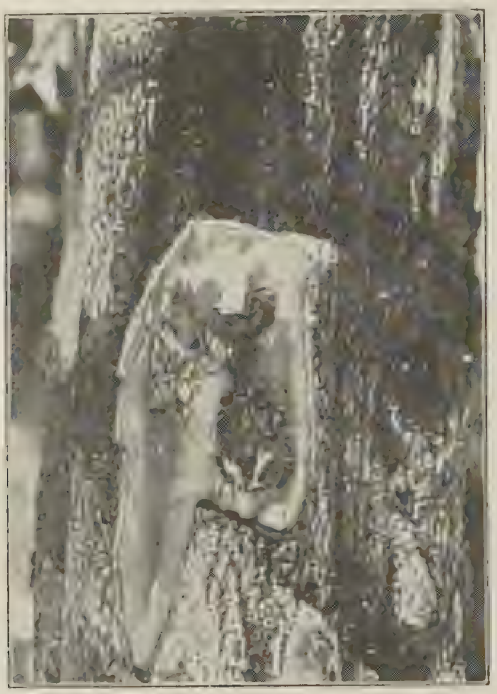

Fig. 44.—Showing a lesion of bark rot when the bark has been cut away and removed. This is the same lesion shown in Fig. 43B which was evidenced by the longitudinal cracks.

Comparison of Bark Rot with Other Diseases.—There are very few diseases with which bark rot would be apt to be confused. Psorosis possibly could be mistaken for bark rot, since the two diseases are identical in their final effects, that is, in the ultimate death of affected trees through the girdling of the limbs or the trunk. The nature of the lesions of bark rot however, is quite different from the lesions of psorosis; bark-rot lesions apparently resulting from a disintegration of the young, actively functioning tissues without gum on the surface, while the lesions of psorosis show, in addition, the stimulation of the cells causing eruption of the tissues and considerable gum at certain seasons. Bark-rot lesions are accompanied by the white ooze, as shown in Fig. 43; this white ooze has never been observed accompanying psorosis on sweet-orange trees.

The diseases differ also in the hosts attacked or their degree of susceptibility; psorosis attacks sweet-orange trees and pummelo trees and occasionally tangerine oranges in Florida. Bark rot attacks especially tangerine and true mandarin orange trees, Satsuma orange trees and calamondins.

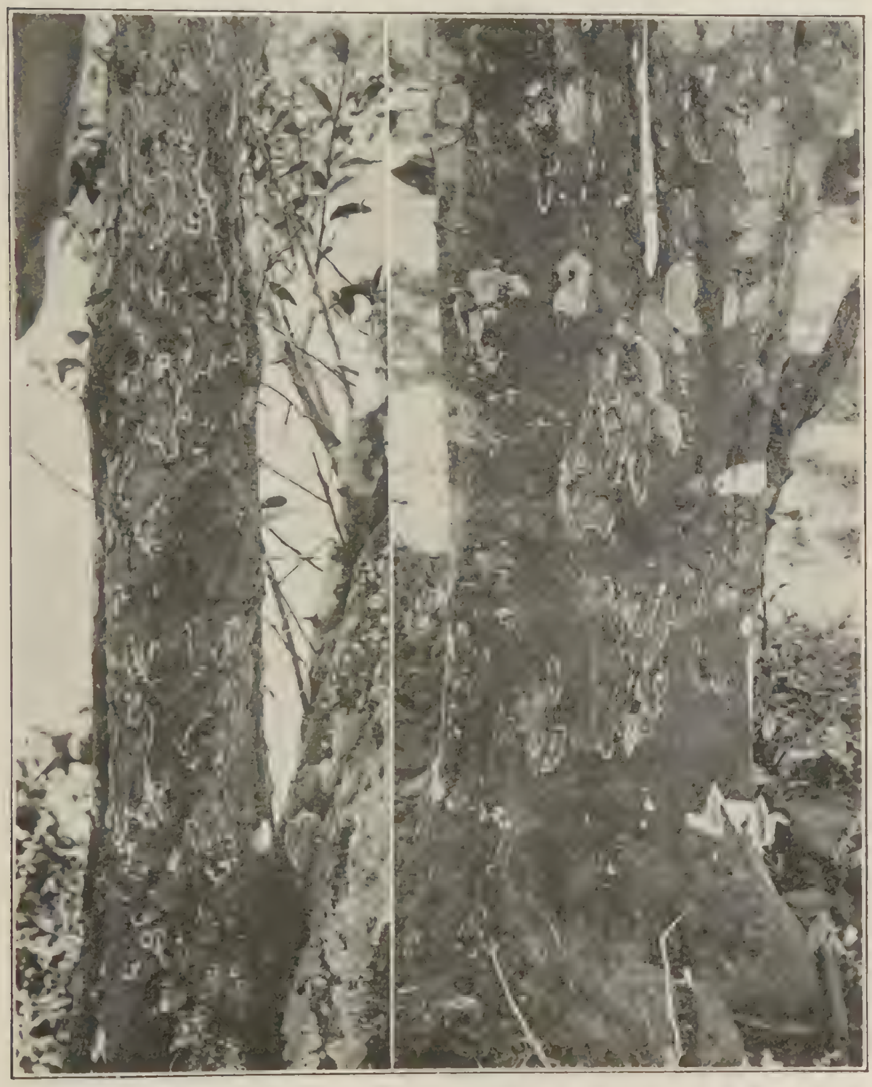

Fig. 45. Old bark rot lesions on mandarin orange tree showing the large areas of bark tissues killed out with the ultimate complete girdling of the limb.

The possibility has been considered of this type of disease being identical with the Diplodia gumming of South Africa and Florida; however, there is no white ooze in connection with the Diplodia disease in those countries such as is characteristic of bark rot. Diplodia infection on Citrus hosts also results in the production of gum from the affected tissues, which is not the case with bark rot.

Mal di gomma and similar types of gummosis in California and Florida differ from bark rot in that they are usually confined to the base and trunk of the tree, whereas bark-rot lesions extend well up into the tree 6 or 8 feet above the ground. Bark rot in the Philippines as compared with these diseases also differs in the non-production of gum.

Prevention.—There is some slight evidence to indicate that spraying with fungicides such as Bordeaux mixtures or lime sulfur will minimize the injuries from bark rot, but extensive field experiments are necessary to corroborate the small amount of evidence which is now available. Spraying, however, is an expense which must be borne repeatedly, year after year, and it is probable that for countries where bark rot occurs the growth of resistant varieties or species would be ultimately more economical. In tropical countries, however, the Washington Navel, sweet oranges of Florida origin, such as the Parson Brown, Magnum Bonum, etc., do not produce so desirable a fruit as the mandarin-orange varieties. For this reason, it may be necessary to resort to spraying as a prevention in such countries as the Philippines or South China until suitable resistant varieties are found or developed.

For those countries where the disease does not occur as yet, such as Java, Australia, Hawaii, California, Florida and all Citrus-growing countries of the western hemisphere, the cheapest and most effective prevention is obviously exclusion. Should total exclusion fail in some instances, total eradication of small affected areas would be more economical than spraying expenses for a whole country, repeated year after year.

DECORTICOSIS OR SHELL BARK

Decorticosis or shell bark is a disease affecting the outer layers of bark principally on the trunks of lemon trees (*Citrus limonia*). In some instances, the disease spreads up on the bases of the larger limbs, but, in general, it is confined to the bark on the trunk. It is not known to affect anything except the lemon bark. The general aspects of decorticosis suggest the loosening bark that is normal to the shell-bark hickory tree of the eastern United States. This resemblance spoken of by Fawcett (1915*a*) in describing the disease led Coit and Blanchard (1922) to employ the term "shell bark." Shell bark is frequently confused with psorosis of sweet-orange trees (*C. sinensis*), which is a very different manifestation and which never spreads to the lemon bark.

Distribution and History.—It is not known how widely the disease occurs in the various Citrus countries. It does not appear to have attracted any attention in California until recent years. It was already fairly common in many orchards, however, in 1912, when the senior author began his investigation of Citrus diseases in that state, but no definite mention of the disease had been seen in previously published accounts. A similar condition was seen on lemon-tree trunks in Florida and Cuba in 1914 and in Sicily in 1923 (Fawcett 1915*a*, 1925*d*). A fungus species, *Phomopsis californica*, has been shown to play a part in the development of the disease in California (Fawcett 1922*b*).

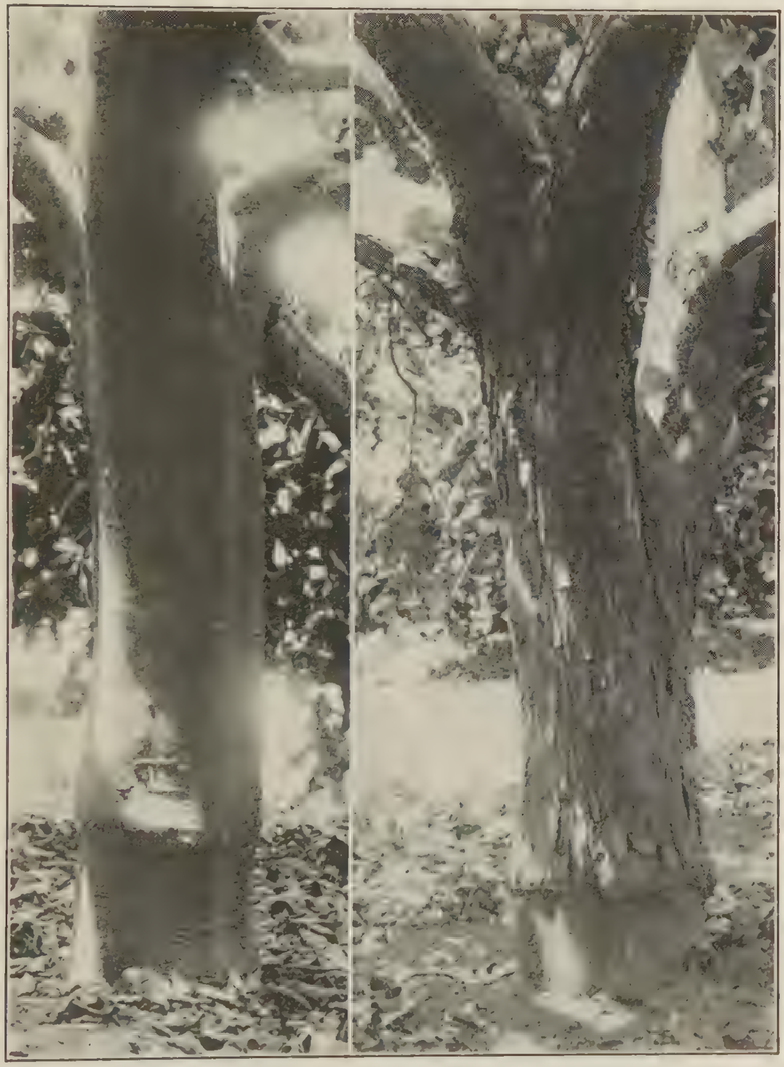

Fig. 46.—A, showing normal smooth bark of a lemon tree trunk about 20 years of age; B, lemon trunk in same orchard affected with decorticosis or shell bark with the exception of the sweet orange stock below the bud union.

Symptoms.—Shell bark is found only on lemon trees or on trees having lemon trunks of considerable age. The outer bark dies, shrinks, cracks and, in advanced cases, tends to loosen in vertical strips. The drying and cracking of the outer bark frequently starts at the bud union near the soil and gradually works upward till the entire trunk is involved (Fig. 46). In cases of shell bark alone, that are not accompanied by gum diseases, the inner bark and cambium remain alive and tend to

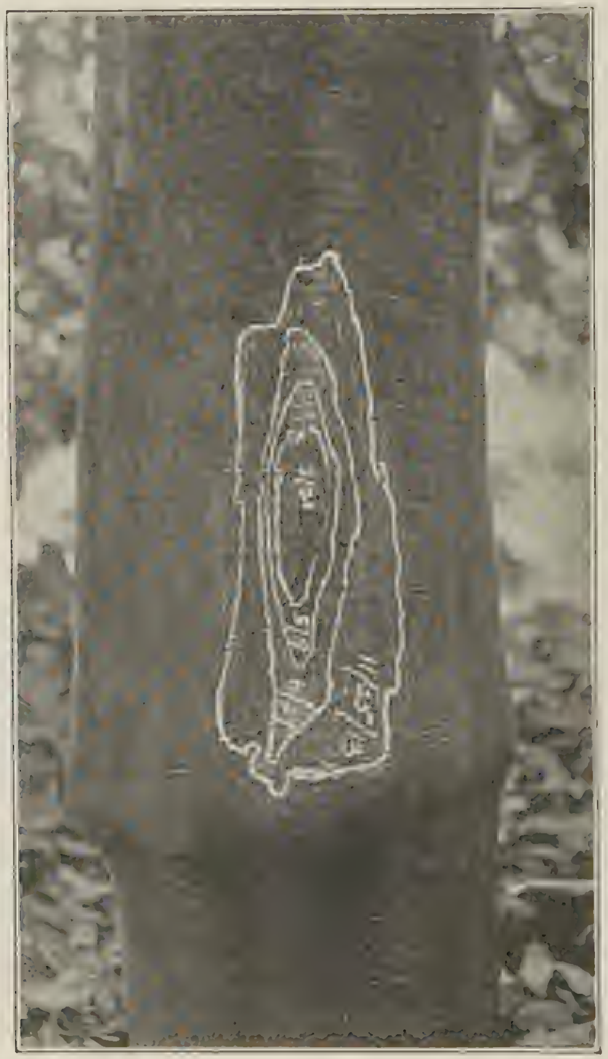

Fig. 47.—Showing slow formation of shell bark lesion on Lisbon lemon trunk. White lines show size of area on February 21, May 9, June 27, and November 13. Compare with Fig. 46B.

build up new layers to replace the outer destroyed layers. Young bark appears to be immune to the disease, which is found only in connection with bark of a considerable age.

The general effect on the foliage and appearance of the tree may be quite marked when shell bark is advancing rapidly in the bark tissues. The leaves gradually turn bronze color, some of them fall prematurely, leaving a rather sparse foliage or bare twigs, the tips of which may die back for a short distance. In less severe cases, there may be only an indefinite "off color" and lack of vigor without any definite symptoms in the top of the tree.

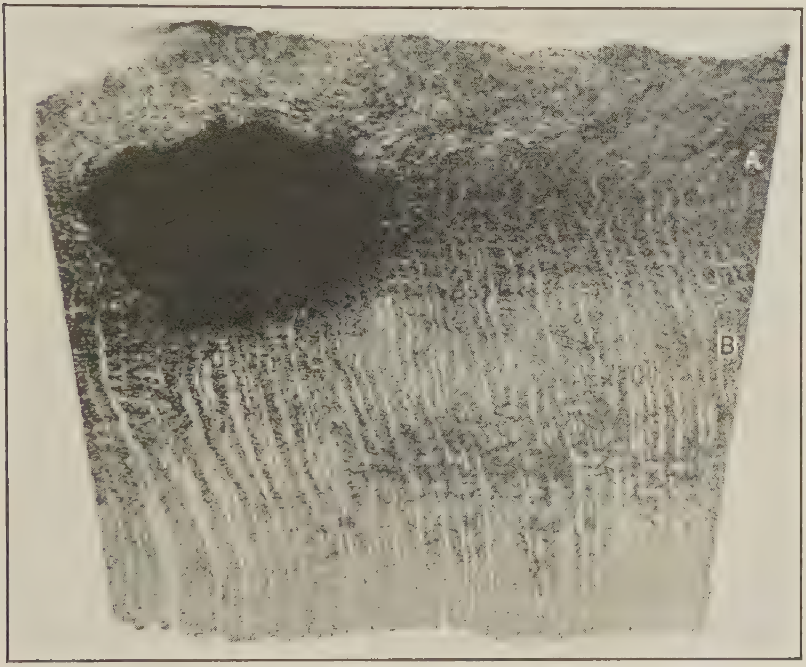

Fig. 48.—Cross section of a bit of lemon bark, cut across one of the internal extensions of a shell bark lesion, as if one were looking downward with the exterior of the bark at the top of the illustration. The affected portion in black is located partly in the outer cortical layers (A) and partly in the conducting layers (phloem) of the inner bark (B). The light lines represent the medullary rays between the portions of the phloem which contain the conducting vessels or sieve tubes. Magnified about 15 times.

After the entire outer bark of the trunk has been involved and begins to crack and loosen in strips, and the inner bark begins to build up again, the foliage may again wholly or partially recover its former green vigorous appearance. In certain Eureka lemon orchards where observations have been made over a period of twelve years, shell bark has reappeared in a more or less active state in cycles of about four to five years.

Trees on which the areas of shell bark progress very slowly, as in Fig. 47, may not show any striking damage from its presence. The bark underneath the affected areas has time to recover almost as rapidly as the disease advances, so that no striking effect is noted. The extension of the lesions in many cases takes place in lines or streaks usually from near the bud union upward. The causal fungus advances at first through layers of bark not quite midway between the outside and the cambium, usually involving some of the inside cortical tissues and a small portion of the conducting layers (Fig. 48). For a while the bark remains sound on the exterior but is finally killed over these inner streaks. These streaks and lines, brown in color, may sometimes be traced for many inches beyond any visible effect on the exterior.

Causal Agent.—A fungus, *Phomopsis californica,* discovered in active lesions of shell bark in 1921 by Fawcett (1922*b*, 1924) has been shown by inoculation tests to be capable of inducing the disease. The fungus was isolated from the advancing margins of actively progressing lesions. Small bits of this fungus were inserted into slight cuts in the outer layers of bark. A similar cut in the same trees into which no fungus was inserted healed without reproducing the disease. The shell bark started off slowly from the inoculated cuts as a center and in about two years had covered one-half to three-quarters of the surface of the trunks with typical shell bark. A fungus was then reisolated and found to be the same species. It is usually invisible to the unaided eye in the diseased bark. Under certain conditions, however, the dark pycnidia or spore-bearing bodies are found partly embedded in the surface of the dead strips of outer bark and may be seen with the hand lens. These are about 1⁄100 inch (0.16 to 0.30 millimeter) in diameter and contain numerous colorless spores. This same fungus may produce a pliable leathery stem-end rot of lemon fruits. The fungus is described and illustrated under Phomopsis Stem-end Rots (p. 407).

Contributing Conditions.—Shell bark is apparently more prevalent in the moister sections of California near the coast or along the moister foothills than in the drier interior valleys. Degree of moisture in the atmosphere is probably one contributing condition. The disease is also likely to start in slight injuries or breaks in the outer bark tissues. The most common place for the diseased areas to start is at the bud union, probably at injuries or growth cracks. If the moist soil is allowed to remain against the bark at or above the bud union, a favorable condition prevails for the start and development of the disease.

Susceptibility of varieties and strains is also a contributing condition. Observations regarding this disease indicate that Eureka lemon trees are more susceptible than Lisbon lemon trees and that certain strains within the Eurekas are more resistant than other strains of the same variety. In general, Eureka trees are fifteen to twenty years old before shell bark begins to affect the bark to any extent. Lisbon lemon trees are usually older, twenty to thirty years, before they begin to show its effect, and even then its progress on the Lisbon is usually very slow.

Examples of extremely susceptible strains of Eurekas have been noted on which shell bark began at the age of eight to ten years. When the parent trees, from which these susceptible ones had been budded, were examined, it was found that the trunks and also the bases of the oldest limbs were covered with shell bark. There was indication on the trunks that a new bark had formed, two or three different times, by a repetition of the shelling-off process. Trees from the same source which had been sent to another locality many miles distant also showed this same tendency to contract shell bark at an early age.

A second example is that found in an orchard where twelve trees, eighteen years of age, at the end of a single row, had shell bark, while no trees on adjoining rows had contracted the disease. Further observations showed that these twelve trees were of one type and probably came from the same bud stick. It was later learned that the trees had been budded over to lemons after they had been planted and that the budding over had probably proceeded in the direction indicated by the row of affected trees.

Control.—The control methods for this disease are still in an experimental stage in California. Certain suggestions as to prevention and treatment, however, arise from the knowledge of the nature of the disease and observations regarding the contributing factors.

Prevention.—As in many other bark diseases, the avoidance of injuries to the bark is important. It is expected also that certain disinfectants or fungicides will be a help in preventing the development of the organism. The selection of possible resistant varieties or strains is also a means of preventing the disease in new plantings.

Observations indicate the importance of selecting buds from trees that are free from shell bark after they have attained a considerable age. Such buds will probably be more likely to give trees that are more resistant to shell bark than trees from bud wood taken from a tree, under the same conditions, that has already contracted shell bark. This would be a natural inference from the bud selection work of Shamel, Scott, Pomeroy and Dyer (1920*a*, *b*).

Treatment.—As to whether it is feasible to treat trees for shell bark depends largely on the age of the trees and their degree of susceptibility.

When the disease is just starting on a tree and appears to be progressing rapidly, results so far secured seem to indicate that it is a good practice to scrape not only the diseased area, much in the same manner as is done in the treatment of psorosis of oranges, but also to scrape the entire trunk, being careful to remove only a thin outer layer so as to disturb as little as possible the inner bark and cambium. The trunks can then be treated with some good fungicide, such as is used in psorosis treatment (p. 170). Since the lesions often extend for long distances in the middle layers of bark beyond the visible signs on the exterior, it is usually difficult to treat it successfully without scraping the entire trunk as in Fig. 49.

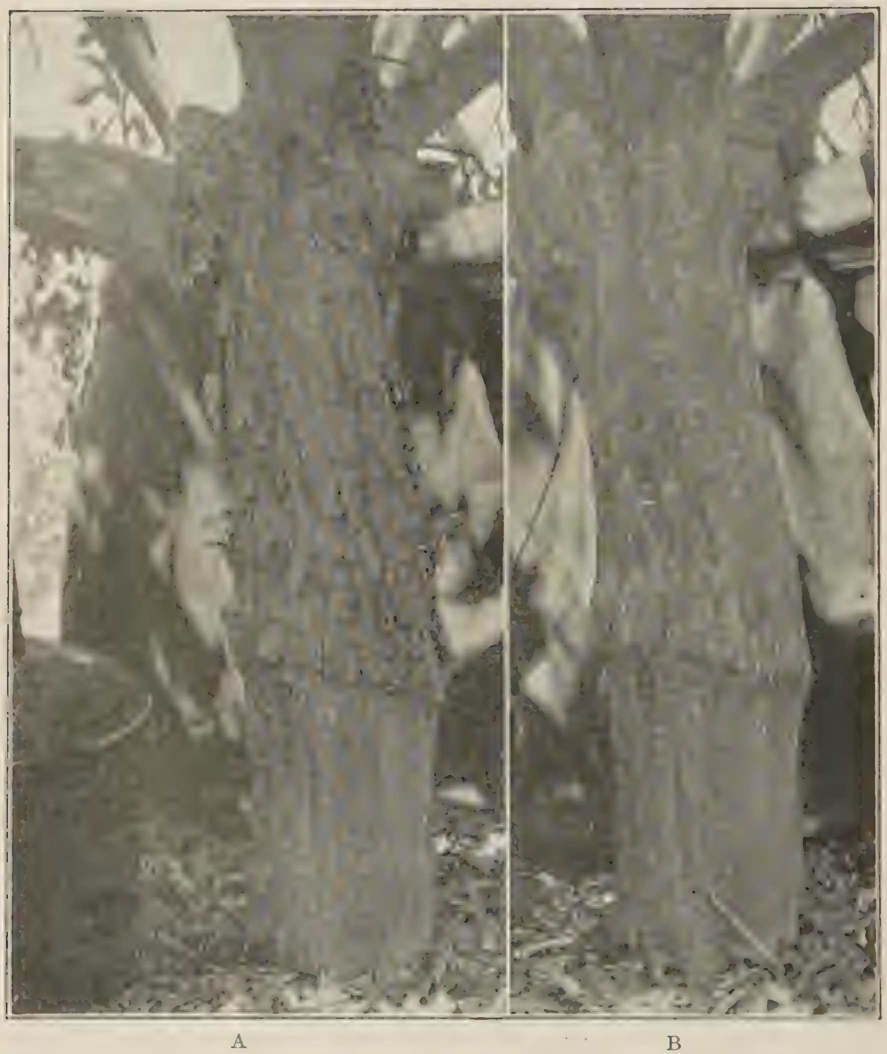

Fig. 49.—Lemon tree with trunk previously scraped for treatment of shell bark: A, showing thin dry scales peeling off and hanging loosely as the result of treatment a year or more before; B, same tree after thin scales have been rubbed off to show the new bark underneath.

It seems advisable also to thin out the branches in the top at the same time that this treatment is given.

When the shell bark has already involved the entire trunk, or a greater portion of it, and a new bark has been formed underneath and the old is shelling off, it is uncertain whether a severe scraping is then advisable or economical, especially on trees where the disease is progressing slowly and is not complicated with gum diseases such as Botrytis gummosis or other forms of gum diseases. When gum diseases follow or accompany the shell bark, they should, of course, be treated.

BOTRYTIS GUMMOSIS

This type of gummosis due to the fungus *Botrytis cinerea* Pers. was shown to be distinct from other gum diseases on lemon trunks by Fawcett (1913*b*). The same fungus is responsible for Botrytis twig blight and for an important rot of the fruit (Chaps. XIV and XVI).

Geographical Distribution.—As a gum disease of the trunk and larger limbs, it appears to be confined largely to the lemon in California and to the moister, cooler coastal regions. Species of Botrytis, however, have been reported on Citrus in southern Europe and Australia by various authors: Penzig (1887), Cavara (1891), Brizi (1903), Janini (1923), Ferraris (1913), Brittlebrank (1915), Adams (1923). Its occurrence on Citrus in Florida, Cuba or the West Indies does not appear to have been reported. The fact that the fungus grows best at comparatively low temperatures may account for its unimportance in these localities. In California, the fungus is not active except in the cool, moist part of the year or in packing houses on fruit at moderate or cool temperature.

Symptoms.—Botrytis gummosis differs from Pythiacystis gummosis and mal di gomma in that it causes softening of the invaded bark in the early stages. A gray-colored furry mat, due to the fruiting bodies of the fungus, may also occur on the surface in damp, cool weather (Fig. 51). If, however, the air is dry, this surface mat may be absent.

In the later stages, the outer layer of bark is killed and becomes dry and hard much in advance of the inner layer, while there is a greater tendency than in Pythiacystis gummosis for the tree to renew the bark underneath the dead layer, and there is usually also a less copious flow of gum. Unlike Pythiacystis gummosis and mal di gomma, Botrytis gummosis is confined, under California conditions, almost exclusively to lemon trees growing in the coastal regions and usually occurs on trees that are more than ten years of age.

This disease should not be confused with decorticosis or shell bark (p. 176), a desquamated bark condition in which the outer bark of a lemon tree dies, cracks and breaks away in longitudinal strips, a condition which is somewhat similar to that frequently brought about in the later stages of Botrytis gummosis. These two diseases are often associated on the same trees. The conditions favorable to the one are also apt to encour-

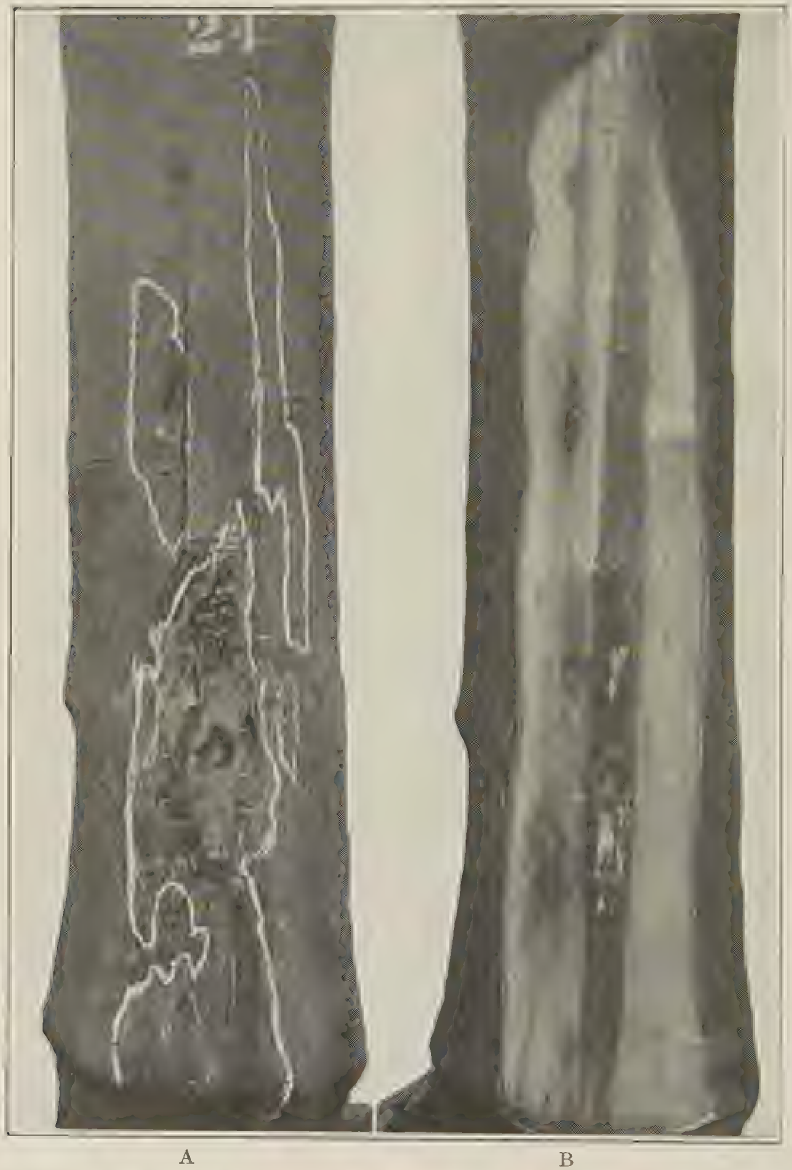

FIG. 50.—Botrytis gummosis induced by a medium heavy blow from a hammer on a lemon trunk, the wound being immediately inoculated with *Botrytis cinerea*. A similar blow on the opposite side without inoculation healed without gumming or serious effects. A, Chalk lines indicate limits of effects seen on the outer bark 9 months after inoculation. Gum is oozing at several places. B, Bark removed to show effects near the cambium region. A gum pocket is seen near the top not occupied by the fungus but induced by the influence of the fungus from below. The dark bands indicate gummous zones extending beyond the regions actually invaded by the organism.

age the other. Neither disease should be confused with psorosis of sweet orange trees (p. 158).

Development of the Disease.—Unlike *Pythiacystis citrophthora*, the causal fungus, *Botrytis cinerea*, is usually not able to gain entrance except through some wound or defect in the bark and is not able to progress so rapidly in killing the bark through to the wood. A large area is involved, in which only certain outer layers of bark tissue are killed, leaving the cambium alive and capable of renewal. This gummosis also produces an outer gummous zone beyond the invaded area, but this is usually less extensive and less rapidly formed, and there is usually somewhat less gum formation than in Pythiacystis gummosis and mal di gomma (Fig. 50).

On cutting into the diseased lesions, it is frequently found that a small region of inner bark and the first wood layers are in a state of disintegration accompanied by a watery gummy formation. The Botrytis fungus readily dissolves the cellulose walls, especially of the bark cells, in a manner in which neither the Pythiacystis nor Phytophthora fungus are capable. This accounts for the characteristic softening of the tissue in the early stages. The inner bark and the surface layers of the wood usually become a mineral-brown color, and the outer gummous zone beyond the invaded portion becomes yellow ocher to chamois-yellow color (Ridgway 1912), just as in Pythiacystis gummosis and mal di gomma. The gum itself on the surface takes on the same color in all the gum diseases varying from a mahogany to chestnut in color. The bark remains soft at the center of the lesion only at first when the fungus has actively invaded it. The bark, soon after, dries, shrinks and cracks from loss of moisture or becomes impregnated with gum, which on drying becomes hard and brittle or is dissolved away by rains.

Causal Agent.—Investigations carried on with a series of inoculation and isolation tests begun in 1912 in California by Fawcett (1913*b*, 1923*a*) showed that a strain of the fungus *Botrytis cinerea* was responsible for this type of gummosis. The fungus, when isolated from decaying lemon fruits in the packing houses, produced the same results as when isolated from gummosis lesions. The fungus was isolated from the softened invaded area of a large number of these lesions. Attempts to isolate the fungus from the outer gummous zone, however, failed, just as they did in Pythiacystis gummosis. The presence of the fungus on diseased lesions becomes evident usually in rather moist cool weather. A light-gray growth appears, soon turning darker gray or grayish brown. This growth is made up of vegetative hyphæ on which is borne the outwardly extending fruiting hyphæ (conidiophores) bearing the numerous spores at the ends of their branches. These vary in size according to surrounding conditions (Fig. 51).

A strain isolated from Citrus and grown on corn-meal agar produced globose spores 8 to 12 by 7.5 to 10μ. *B. cinerea* Pers. as described by Rabenhorst has hyphæ gray,

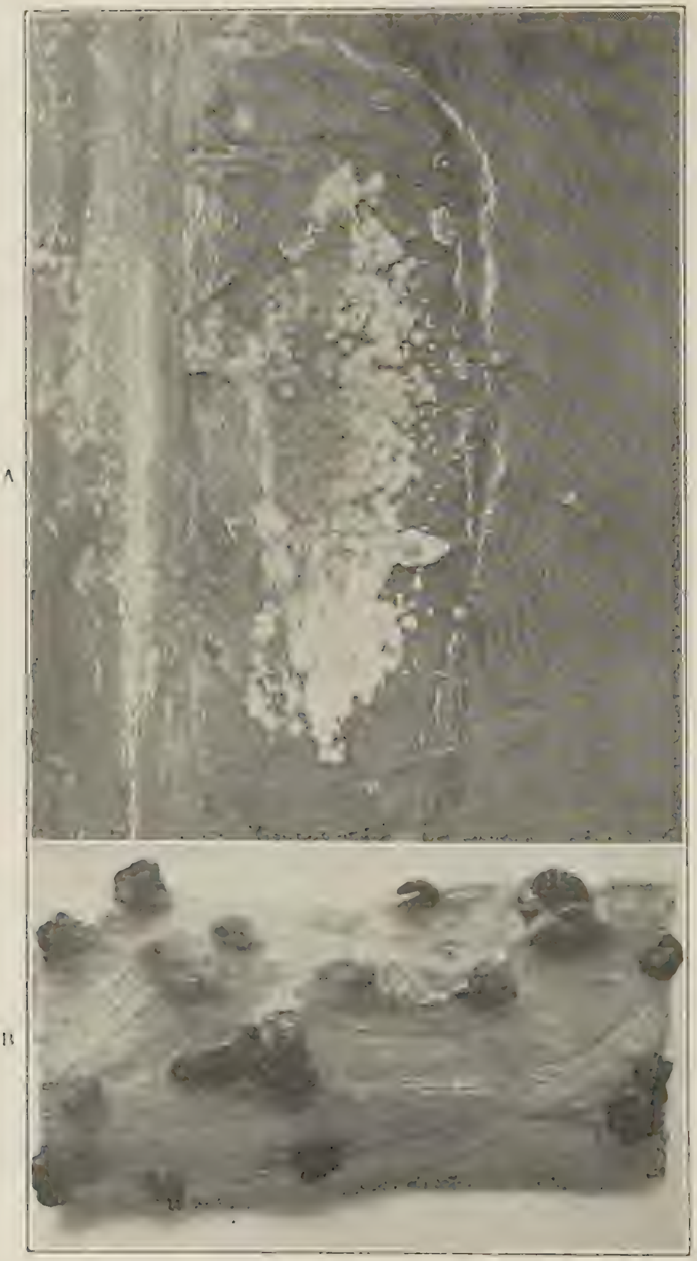

Fig. 51.—Forms of the Botrytis fungus. A, Gray masses of spores on the surface of the bark in moist weather about natural size. B, Small black sclerotia in cultures on orange wood, magnified about 2 times.

greenish gray or dark olive, conidiophores septate 11 to 23μ in diameter with dark-brown tint, branches hyaline with rounded ends, each ultimate branch bearing three or more globose pale-colored spores. The spores are 9 to 12μ long by 6.5 to 10μ broad (Fig. 128). This fungus develops sclerotia (Fig. 51) in culture media, but these have not been seen on the diseased bark. They vary in size, but may average 5 to 8 millimeters in diameter. Appresoria also frequently develop in culture media.

At first, there is no evidence of the presence of the fungus on the surface of active lesions. If, however, the air is moist, abundance of conidiophores and spores appear, extending out from the surface in a continuous mass, gray to grayish brown in color.

The fungus lives on a variety of decaying matter, such as leaves, twigs, fruit, bits of wood or other vegetable matter in or on the soil. The spores may be carried by wind, water, insects or other carriers to the surface of the tissues where they may germinate and enter wounds. Under favorable conditions, the fungus may gain entrance to uninjured tissue if this uninjured tissue is in direct contact with organic matter or dead cells into which the fungus has first penetrated. Smith (1902) describes the action of the fungus on tissue as "a disintegration of protoplasm, separation of the cells one from the other, and finally a collapse, the tissue being affected at considerable distance from the fungus filaments."

Contributing Conditions.—Many contributing conditions tend to favor the occurrence and the severity of this disease. Some of these are similar to those which favor Pythiacystis gummosis, as discussed under that disease (p. 135).

Injuries of various kinds to the bark, not only near the soil, but anywhere on the trunk or large branches, may lead the way to infection and development of Botrytis gummosis when the conditions of moisture and temperature are also favorable. This disease is frequently severe on living tissue of trees that have been injured by frost. The fungus may first become established in such trees in a small portion of dead or dying tissue and then advance rapidly into tissue which appears to be sound.

Botrytis gummosis is also frequently associated with shell bark, which is fairly common on old lemon trees in the California coastal regions. The dead outer bark tissue of shell bark furnishes a suitable medium from which Botrytis may advance into sound tissue. Shell bark is somewhat similar in appearance to a condition which usually follows inoculation with *Botrytis cinerea* on sound tree trunks and which is often confused with Botrytis gummosis.

The previous use of neat's-foot oil in the treatment of gummosis in California encouraged the growth of the Botrytis fungus. The trunks of lemon trees treated by scoring or slitting the bark and painting with neat's-foot oil were observed in February and March of 1912 to be fairly well covered with a gray coating consisting of the sporophores and spores of Botrytis. The bark on these trees was found to be in various stages of soft decay with the exudation of large masses of gum. Experiments also showed that this fungus developed better on lemon bark treated with neat's-foot oil either before or after infection by the organism than on bark free from this oil. More recently the application of neat's-foot oil to Citrus trees has been largely given up, and the more severe stages of this disease, such as were previously seen, have not been observed.

Control.—The methods of prevention and treatment are similar in principle to those discussed in connection with Pythiacystis gummosis and mal di gomma. A few modifications, however, based on the differences in this disease should be pointed out.

Prevention.—Since *Botrytis cinerea* appears to be dependent upon abrasions or other injuries for its entrance into lemon bark, especial care is necessary, particularly in moist weather, to avoid injuries in cultivation, picking and other orchard operations. The danger from such injuries may be lessened by painting the tree trunks with Bordeaux paste or other fungicides, or spraying them thoroughly with Bordeaux mixture. The precaution previously mentioned of pulling away soil that is too high against the trunk and of keeping water as much as possible away from the trunk are also applicable in the case of Botrytis gummosis.

Treatment.—The principle governing the treatment of this type of gum disease is the same as that for Pythiacystis gummosis, namely, the elimination of the invaded tissue and the prevention of further progress of the disease. As the result of many different experiments in which growers took a prominent part, a method consisting largely of scraping off the outermost layers of bark was found, which proved to be best adapted for treatment of this disease (Fig. 52). The portion where the bark is totally killed is cut away, but beyond this, where usually only the outer layers of bark are dead, these outer layers only are scraped off, leaving intact the live inner layers next to the cambium. To prevent further invasion of the outer bark, it is usually found necessary to scrape the sound bark several inches beyond the margin of the affected region. A sharp curved tool, described on page 170 and easily controlled in scraping, is in general use for this purpose (Fig. 41). This modification of the method used for Pythiacystis gummosis and mal di gomma is advisable because of the different nature of the disease, and in order to preserve as much as possible the inner live bark. Where two or more types of gummosis are present on the same tree, as is frequently the case, this method is still applicable to the combined lesions produced. The cut or scraped portions are then painted with a fungicide (Fig. 52). Bordeaux paste, some of the coal-tar products, such as Avenarious carbolineum, and Arrow carbolineum, which contain only the heavier oils, have given good results. Mercuric cyanide ⅕ ounce to 3 quarts (1 gram to 500 cubic centimeters) of a watery solution containing one-fourth alcohol or equal strength of mercuric chloride may also be used (Chap. VI).

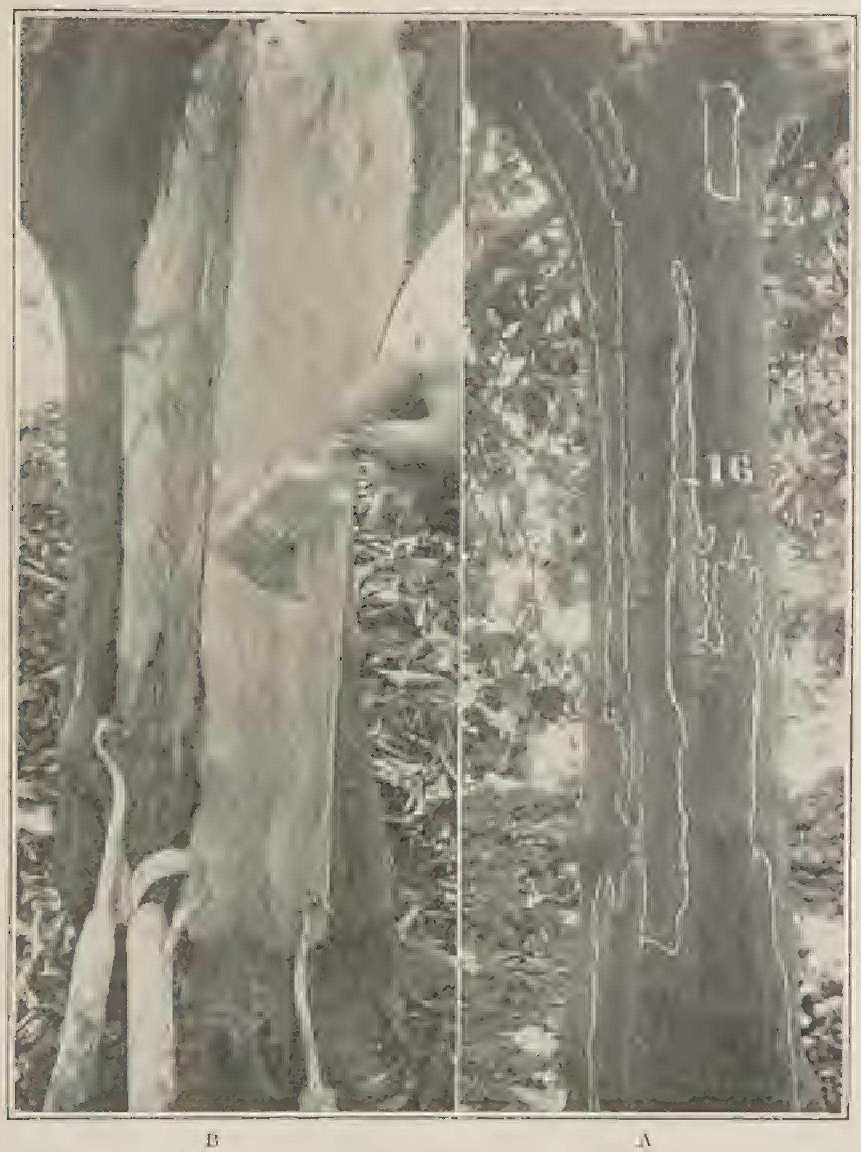

FIG. 52.—A, Combined effect of Botrytis gummosis and shell bark on lemon tree about one year after the two diseases began to spread together. B, lemon tree being treated by scraping method for combined effect of Botrytis gummosis and shell bark.

DIPLODIA GUMMOSIS

A disease affecting the bark and wood of the trunk and larger branches, usually accompanied by a considerable flow of gum to the surface, has been shown to be due to a fungus similar to *Diplodia natalensis* Evans (Fawcett 1912*c*).

History and Distribution.—The relation of a fungus similar to *Diplodia natalensis* to the gumming and death of Citrus and peach branches in Florida was studied by Fawcett and Burger (1911*a*) by means of a large number of inoculations with pure cultures. It was also shown to be capable of killing bark and inducing gum on a large number of native trees, including wild plum (*Prunus umbellata*), wild cherry (*P. serotina*), cherry laurel (*Laurocerasus caroliniana*), prickly ash (*Xanthoxylum americanum*), sumac (*Rhus gladra*) and sweet gum (*Liquidambar styraciflua*). Bleeding was induced in other trees, as basswood (*Tilia pubescens*), red bud (*Cercis canadensis*), hackberry (*Celtes georgiana*) and mulberry (*Morus sp.*) (Fawcett 1912*c*). Evans (1910) had described this fungus previously in connection with a decay of lemon fruits in South Africa. The same fungus was also found commonly in Florida in connection with a decay of fruits (p. 409).

A similar fungus was later reported by Earle and Rogers (1915) in connection with a bark disease of Citrus tree trunks in the Isle of Pines, Cuba. They also reported its occurrence there on twigs, leaves and fruit. The same or a similar fungus is found on twigs and roots of limes in various parts of the West Indies (p. 308). The fungus was isolated by Fawcett (1913*a*) in fruit arriving from Porto Rico and has been reported in Porto Rico by various workers.

A fungus similar to this Diplodia has also been found in California, producing bark and wood rot and accompanied by gumming (Fawcett 1923*b*, 1925*d*). It has also been found producing a stem-end rot of Citrus fruits, especially mature lemons (p. 410). Species of Diplodia presumably different from *D. natalensis* are reported in Brazil, Egypt, southern Europe, India, Australia, South China and the Philippines. *D. natalensis* or related species are probably world wide in distribution on Citrus trees, the injury from them varying with differences in climatic conditions or virulence of the strains or varieties.

Symptoms.—Diplodia gummosis as a bark disease of the trunk or larger branches has symptoms in common with some of the forms of gummosis previously described. As in other forms of gummosis, one of the first visible signs that call attention to its presence is gum oozing out on the surface. In milder cases, the injury may be confined principally to small patches of bark at certain seasons of the year, and these later partially heal underneath leaving a scar. In severe cases, large areas of bark are killed, and the wood becomes blackened and dead by the further invasion of the organism. Frequently, the organism extends along the wood tissue much more rapidly than it invades the bark. The bark often presents a resistance to invasion which halts the progress of the fungus, while it still continues to invade the wood inward.

In branches or trunks weakened by cold or other causes, especially where large portions of the tree have been cut away, the organism may advance as a "heart rot" or "wood rot." The wood is at first merely discolored without apparent breaking down, but this opens the way for wood-decay fungi, such as species of Stereum, Polystictus, Schizophyllum, etc., which soften and make punky the interior of branches or trunks so affected. The causal fungus is described under Diplodia rot, on page 411.

Contributing Conditions.—Some of the conditions contributing to the occurrence and development of Diplodia gummosis are thought to be unfavorable climatic conditions, such as extremes of cold or heat, wounds, weak and deteriorated mature tissues, etc. The fungus found in connection with this gummosis is especially active in California after a severe freeze. It has been found advancing into the yet unkilled wood of large branches which have been cut off after a freeze. Large areas of live bark are also killed, and gum is exuded in considerable quantities under these conditions. Earle and Rogers (1915) state that "actively growing tissues have considerable power of resistance. No tissue seems to be attacked until it is fully matured or until enfeebled from unfavorable conditions."

Control.—In this type of gummosis, the wood as well as the bark is invaded by the fungus, and the invasion of wood is likely to be far beyond that shown by the dead areas of bark. For this reason, it is much more important to cut a greater distance beyond the apparent effect upon the bark than in most other types of gummosis. If lesions are discovered when new at wounds on large trunks, the affected bark and any discolored wood underneath should be removed and the wood painted with a disinfectant and later with a good covering (see p. 196). In case a limb is affected, it should be cut out well back into the live wood and the cut surface disinfected. This fungus is very resistant to certain sprays, such as Bordeaux. In some experiments by the author, it was found that this fungus in cultures could endure a strength of copper sulfate about ten times as strong as that required to stop the growth of *Pythiacystis citrophthora*.

DOTHIORELLA GUMMOSIS

A form of gummosis similar to Diplodia gummosis on lemon trees in California has been shown by recent experiments to be due to a fungus similar to *Dothiorella ribes* Gross and Dug. Gum in considerable quantities oozes from a fusoid gum pocket on the trunk or large limbs. This form has been referred to by some growers as "pocket gum." The dead-bark areas vary in size, but are usually not extensive. The inner bark tissue is often disintegrated and dissolved, leaving elongated cavities and grooves in the inner bark next to the cambium region. The inner bark is chocolate brown. The wood below the pocket is often discolored inward for a short distance beyond the cambium. There is also a gummous zone near the cambium as described for Botrytis and Pythiacystis gummosis. There is a tendency for these lesions to become self-limited before becoming extensive and to fill up with new bark tissue at certain seasons and to become active again at other times (Fawcett 1925*d*).

The same fungus that causes Dothiorella gummosis is also responsible for Dothiorella rot of fruit (p. 412). The contributing factors and control would probably be the same as those given for Diplodia gummosis (p. 191).

CONCAVE GUM DISEASE

This disease, which has been observed in two or three localities in California, usually in Navel oranges of considerable age, is apparently not generally distributed. Its most characteristic feature is a rather broad concavity on the side of a limb or trunk for the most part covered with normal bark, but showing somewhere within the broad depression an irregular formation of abnormal tissue with a crevice or crack through which gum usually oozes to the surface at certain seasons. These concavities vary in size but may be 3 to 6 or more inches in length and half as broad. They are formed by an arrested growth of wood tissue at certain places.

When the bark over one of these concavities is removed, a mass of gummy granulated tissue is found. This is often cinnamon to tawny or russet in color. Cutting deeper, the underlying layers of wood are found impregnated with semiliquid to cheesy, gummy substance extending over the entire concavity and sometimes out beyond its edges for some distance. The concavity appears to have originated from slowing down of wood growth over a certain region; somewhere within will usually be found evidence of dark tissue, showing a place where a former twig or branch has been broken or cut off, leaving a short stub or bit of dead tissue concealed by subsequent growth of the wood and bark. There are found few to many successive gum-filled layers of wood alternating with layers of nearly normal wood. It would appear as if a gummy layer had formed at a certain season each year just inside the cambium, and successive layers of wood had formed over it at other seasons. Not far beyond the margins of the concavities the gummy stains or layers in the wood disappear.[1]

---

[1] A Phoma-like fungus has been found by culture tests generally present within the darker tissue of the wood in most of the concavities of this kind so far examined.

The injurious effect is very slow, but where the lesions are large and numerous the trees have been killed apparently from the presence of this disease.

J. C. Perry of Highlands, Cal., who first called our attention to the concave gum disease and the blind pocket, states that he has cured many cases by gouging out all the stained discolored wood, and cutting slightly beyond, especially at the top and bottom.

BLIND POCKET

This disease has been observed on Navel trees in only one locality in California. This condition is made evident by round or elongated depressions on the large limbs or trunk. The much-elongated depressions are composed of two or more blind pockets close together. A cup-like depression 1 to 2 inches in length with normal bark is formed. The sides are rather quickly depressed or more deeply cupped than in the concave gum disease. When this depressed region is cut into, there is found just under the depressed surface a core of tissue, ochraceous salmon in color, infiltrated or impregnated with a hard, gum-like substance. This may extend 1 to 1½ inches from the surface within the layers of wood. Only rarely is gum forced out to the surface from these blind pockets. So far as observations have been made, no pronounced harmful effects equal to that of concave gum disease have been noted.

BARK SPOT OF BRAZIL

A bark spot on orange trees in Brazil is described by Noack (1900) as probably due to the fungus *Didymella citri*. It is reported to be quite similar to sunburning in some of its stages, but evidently has no relation to sunburning. It first appears on narrow limited places of the bark on the trunk and branches.

The bark is at first raised, but later becomes sunken and dry. The spots vary in size, the smallest ones being 4 by 9 millimeters. The affected patches of bark loosen by a very small pressure, forming a slight depression, which at first does not extend to the wood. Later the bark begins to dry out inwardly and sideways from this first depression, and finally the bark is loosened in larger flakes down to the wood. When this process goes on for a long time, the limb or trunk dies.

On staining the tissue and examining it microscopically, Noack found that the mycelia were present in the still living parenchyma, spreading mainly in the middle layers. The bark becomes brown in certain places, the cells become thick walled and the tissue becomes a pseudoparenchymatous mass. The sloughing off of the bark is due to meristematic formation from below. The affected area is covered with a yellowish gummy mass, in which large thin-walled cells are wholly embedded.

Underneath there is a large thin-walled parenchyma parallel to the wood. Under the whole affected area, there spreads to a certain distance a clearly recognizable meristematic tissue. A complete protection for this deeper bark tissue is not obtained, because even these meristematic tissues are partly impregnated with the mycelium. Finally, the whole bark is destroyed and either remains attached to the wood or scales off. Later the exposed wood may also die.

The pycnidia of the fungus are found in bark recently diseased. They are 2 to 4 millimeters in diameter and are formed close under the outer bark. This disease was observed only on the mandarin. Since no inoculation experiments were made, it cannot be said with certainty that this fungus is wholly responsible for the disease; in fact, Noack mentions finding other organisms which he thought might also play a part.

MISCELLANEOUS TYPES OF GUMMOSIS

Gum formation in Citrus is a common phenomenon in connection with a considerable number of different Citrus diseases, although it is much more evident with some than with others. Since the gum is of nearly the same nature under whatever influences it has been formed, it is not a diagnostic character in itself, but must be considered in connection with other symptoms. Although copious exudation of gum on the trunk or branches is usually found only in connection with the so-called gum diseases or occasionally with severe chemical injury, gum exudation small in amounts may occur with almost any malady. Apart from the so-called gum diseases, small amounts are common at times in connection with exanthema, Armillaria root rot, Citrus blast, Citrus canker, Sphæropis knot, anthracnose of twigs and occasionally with almost any of the other diseases. Dry hot weather is especially conducive to acceleration of gum formation in Citrus.

A form of gummosis on orange and grapefruit trees has been observed in Tulare County, California, following a cold winter with frost. Large branches are killed and dead bark lesions also appear on the trunks, accompanied by much gum formation in large pockets under the bark. The bark after being killed becomes filled with black mycelium of a fungus which appears to be Torula. The spores form during hot weather in a black powdery layer just under the epidermis. Cultures from all parts of lesions show the presence of this fungus. Further investigation is needed to determine what part, if any, this fungus plays in the disease.

In Florida a form of gummosis has been noted by Stevens (1918) which he considers distinct from psorosis. In some of its stages it resembles psorosis, in others Diplodia gummosis. A small definite area is formed on trunks or larger branches. The bark is killed down to the wood and sometimes the wood is penetrated for a short distance. The lesions are from ½ to several inches in extent. At first the bark has a water-soaked appearance with a more copious flow of gum than in most cases of psorosis. In this it suggests Diplodia gummosis. Later the dead bark hardens and cracks, the surface scales in flakes or strips and a new bark tends to form over the affected place. The flakes of bark fall away and leave a brownish scar with a rough surface. In this latter characteristic, it resembles a stage of psorosis. It does not, according to Stevens, form a distinct girdling band, except when a number of areas coalesce, nor does it affect small limbs and twigs.

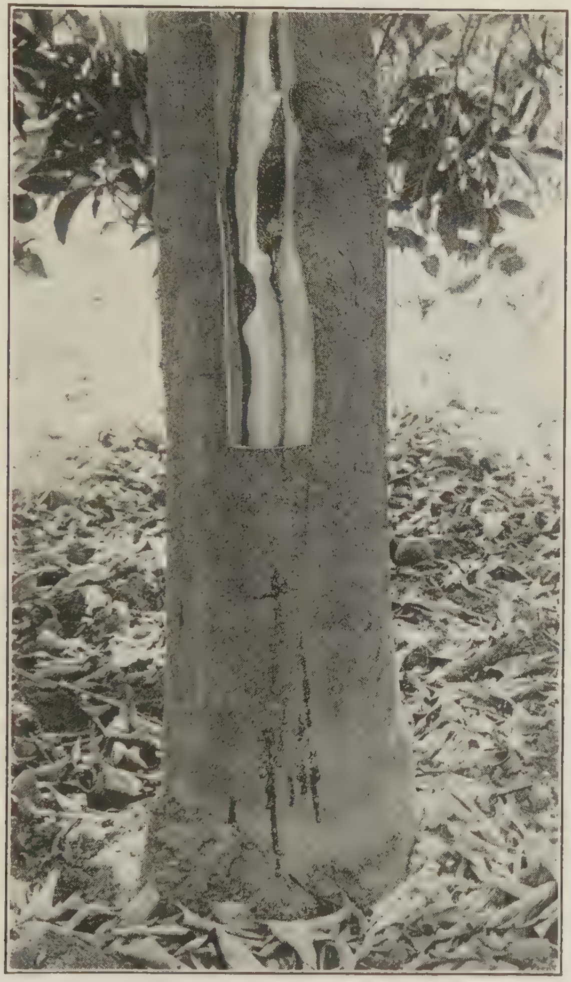

FIG. 53.—Orange tree trunk showing gum formation as a result of using copper sulphate on the soil before irrigation. Roots were injured from which dead streaks with profuse gum formation extended up the trunk. Dark streaks are shown at upper portion where bark was removed. (*Photo by E. E. Thomas.*)

In Paraguay a type of gummosis which Spegazzini (1920) considers to be due to *Bacillus gummis* is reported to be very common, and the order of susceptibility from highest to lowest is reported to be sweet orange, lime, citron, lemon and mandarin, with the bitter or sour orange highly resistant. It also attacks other plants besides Citrus, such as *Mangifera indica, Rheedia brasiliensis, Santalum album, Eugenia jambos,* etc.

Severe gumming may also occur in connection with the attack of the fire ant, *Solenopsis gemmenata,* or other insects causing wounds in the bark.

Gum may also occur on the trunk as a result of chemical stimuli of various sorts. Copper sulfate too concentrated in the soil will induce copious gum formation (Fig. 53). Gum formation occurring in connection with fumigation with hydrocyanic acid gas (Fig. 34), with spilling of cyanide or its products on the roots etc. has been mentioned page 155.

HEART ROTS OR WOOD ROTS

Dead or decayed wood is frequently found in the interior of the trunk or large limbs, especially in trees that have been frozen back severely, that have been top worked or headed back, that have been sunburned, gophered, attacked by gummosis or otherwise diseased, and the wounds not properly cared for.

Two general types of wood decay occur: (1) a hard, firm decay in which the wood is discolored, and (2) a soft punky or spongy decay in which the wood is partially disintegrated Fig. 54, 55. The soft type usually follows the firm, but the firm, discolored decay may sometimes become extensive without the soft form appearing. These types of decay are brought about by many kinds of wood-rotting fungi. They are often supplemented by boring insects or other organisms which enter such wood and help to break it down.

Contributing Conditions.—This wood decay almost always follows injuries of some sort. The sources of wounds or injuries are tools used in cultivation, rodents, gnawing larvæ, excessive water, sunburning, frost, tearing the bark in cultivation, carelessness in pruning or heading back, the presence of bark diseases and the like. In moist climates, the stubs or wounds left in pruning or the death of large limbs are especially subject to the entrance of wood-rotting organisms. It has been observed that the spread of the wood rot in an affected limb takes place at certain seasons, but at others a wall of defense is built up in the wood tissues. This wall appears to be laid down in summer during the rapid-growing season. It consists of a layer of wood infiltrated with a hard, vitreous, gum-like substance which seems to prevent the organisms from penetrating further for a time. When growth is not active, especially in the winter and early spring, this wall of defense is broken down and the wood rot advances again. When wood-rot specimens are cut into, a series of these walls may often be seen, apparently corresponding to successive seasons of rapid growth.

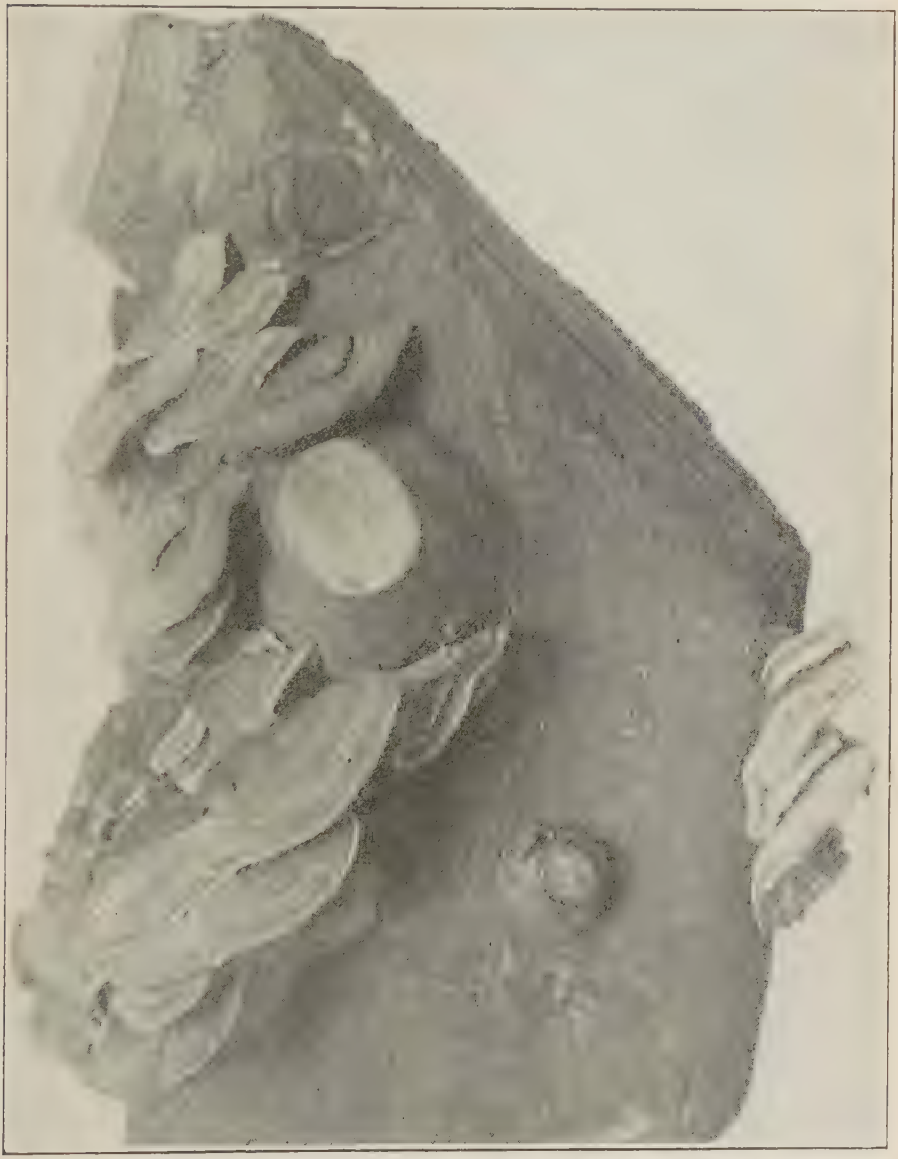

FIG. 54.—Lemon stub containing sporophores of the wood-rotting fungus *Polystictus versicolor* about natural size. (*Photo contributed by Lee Prizer.*)

Causal Agents. The most common causal agents bringing about heart rots or wood rots belong to the higher group of fungi, the *Basidio-*

mycetes. The bracket and semiwoody types of this group are represented by the species of the genera Polyporus, Polystictus, Schyzophyllum, Stereum, Hydnum, Ganoderma, Poria, etc. The soft toadstool type is represented by *Armillaria mellea*, which causes a rotting of the wood as well as a killing of the bark on Citrus roots and lower part of the trunk. *Coprinus atramentarius* has also been found as a secondary organism on the roots of trees, especially when they have been injured by water logging. The effects of *Armillaria mellea*, the oak root fungus, have already been described (p. 89).

Another fungus which produces a white growth on roots injured by too much water, especially in the so-called dry bog soils of the San Joaquin Valley, California, is *Poria vaporiaria* (p. 109). This may sometimes be found spreading also through the soil around the trunks and even on the surface of the yet unkilled bark of the lower trunks. It is thought to be merely a saprophyte living on the dead organic matter of the roots and the soil.

Another fungus, that was found to be important in connection with heart rot after the freeze of 1913 in California in the coastal sections, is a species of Diplodia, similar to *D. natalensis.* This was troublesome, especially on lemon trees that were headed back too soon and on which the cut ends of the large limbs or trunks were covered with some sealing material, such as grafting wax or water-tight paint. Limbs that were so cut back a few months after the freeze, although the wood appeared to be perfectly sound, almost invariably were invaded by the Diplodia fungus which spread rapidly through the interior wood tissue, discoloring and finally blackening the wood (Fawcett 1923*b*). This discoloration was later followed by such fungi as *Polystictus versicolor*, and *Stereum sp.*, producing a punky soft condition of the wood after a year or two (Fig. 55). *Schizophyllum commune* was also found on dead stubs or dead areas. Following the frost, species such as Ganoderma and others were frequently seen. *S. commune* appears to be capable after becoming thoroughly established in the wood to advance slowly into the sound wood and even bring about the death of the bark on the trunk or limbs over the wood tissue that has previously been invaded.

Several kinds of boring larvæ of beetles are found entering the stubs of dead wood left in careless pruning or into dead wood under bark killed by various bark diseases, frost, sunburn, etc. Small beetles known as shot-hole or pin-head borers in Florida may enter the sapwood of Citrus trees in a dry weakened condition and hasten their death. They cannot live, however, in sound, vigorously growing trees (Watson 1918). In tropical or subtropical countries there are other types of borers that bore long distances into apparently sound, healthy Citrus wood, probably entering from dead stubs or weakened tissue.

Control.—The prevention of wood decay in pruning large limbs is discussed in Chap. VII under Pruning in Relation to Citrus Diseases,

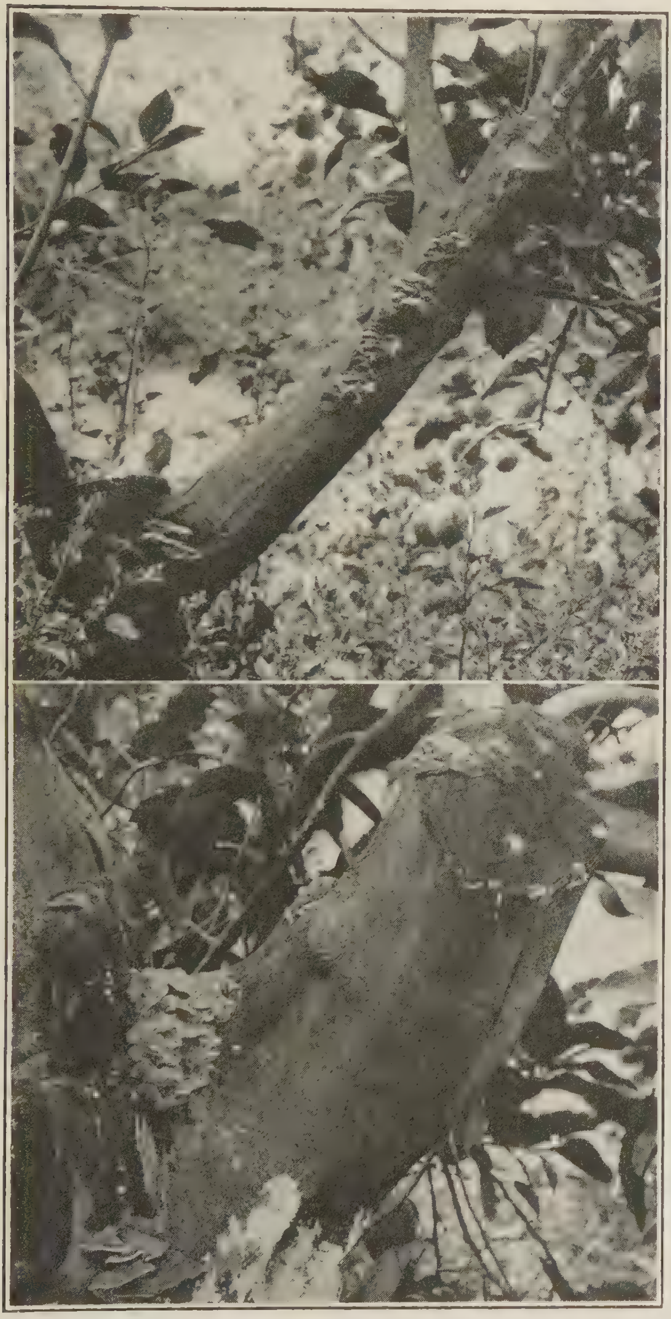

FIG. 55.—Lemon branches on trees three years after the freeze of 1913 in California, showing sporophores of brackets of a wood-rotting fungus, *Polystictus versicolor*. The central part of the wood is soft and punky, while much of the bark is still alive. (*Photo contributed by Lee Prizer.*)

which should be consulted in this connection. The treatment for wood decay, if it has not advanced so far as to make it impracticable, is to remove all the dead and discolored wood and disinfect the wound with some coal-tar product, such as carbolineum or other disinfectants, such as mercuric cyanide or mercuric chloride (Chap. VI), and paint the wound later with asphalt paint, white lead paint or grafting wax. Unless one is sure that all the decay has been gouged out, it is better to leave the wound open, except to prevent borers, than to seal it up with any water-tight paint. Preventive measures against borers consist in properly disinfecting and painting all large wounds or cuts in order to keep them out until the bark has healed over. Weak, dying limbs or trunks infested with borers should be cut out and burned.

If the cavity will hold water, it should be trimmed or cut in such a way as to provide drainage after rains. Cement is not suitable for filling such cavities. Unless some strengthening material is required to support the branches or trees after the decayed wood is dug out, or unless the tree has an ornamental value, it is just as well not to use any material to fill the cavities in Citrus trees. Filling of cavities does not usually pay for the expense incurred, and the open cavities with the wood properly dug out and treated can be inspected more easily for further decay when not filled. The tools for the work in removing decay consist of gouges, chisels, mallets and saws.

For further information regarding the prevention and treatment of wood decay, the details of which are beyond the scope of this book, reference may be made to the books "The Care of Trees," by Fernow (1910); "Practical Tree Repair," by Peets (1913); and to the papers "Practical Tree Surgery" in 1913 *Yearbook*, U. S. Department of Agriculture, by Collins (1914); and "Wood Decay in Orchard Trees, " *Circ.* 137, California Agricultural Experiment Station by Horne (1915*a*).

LICHENS ON TRUNKS

Lichens belong to one of the low forms of plant life in which a fungus and an alga live in close association with mutual benefit to each other. These are commonly seen on the surface of the bark in moist climates or in moist seasons. Lichens together with forms of green algæ are often known by growers as "moss." There are numerous forms of these lichens growing on the surface of Citrus bark in moist situations. These lichens are not in themselves directly harmful to the bark, since they exist entirely on the air or dead matter on the surface. They may, however, under certain conditions be troublesome indirectly by harboring parasites or creating conditions more suitable for the multiplication of the parasitic forms.

One of the commonest forms assumes a greyish-green, paper-like growth covering an area an inch or more in diameter. The edges are lobed and curled and the surface is undulating. A form occurring as a pinkish-white flattened spot closely adhering to the bark is also common in Florida. A partially parasitic alga which might be confused with the harmless lichens is found on twigs and leaves and is described on page 261.

Control.—It is not usually considered necessary to destroy these lichens on the trunks and branches unless they become excessive in amounts and indirectly harmful. When it is deemed necessary to destroy them, a fungicidal spray of Bordeaux mixture or of strong lime sulfur will destroy them. (For fuller discussion of control, see p. 260 under Twigs and Leaf Diseases.)

SUNBURNING

One of the effects of the environment, which is frequently mistaken for certain diseases on Citrus, is sunburning. Indeed, certain bark diseases frequently begin in sunburned areas. Under given conditions, the direct rays of the sun either weaken or kill the bark and make it easy for disease organisms to enter, or they kill or injure certain outer cells causing portions to dry and peel off. Young trees recently planted out or older trees which have been defoliated or recently cut back severely in pruning are especially liable to be injured by sunburning.

This injury is apt to take place as readily, if not more so, in the winter months when the sun's rays are more slanting than in summer when the sun is nearly overhead. It has been found that the bark may be heated many degrees above that of the surrounding air by the rays of the sun. The resulting injury is often mistaken for the attack of certain organisms. The injury caused by the sunburning, however, may make it possible for these organisms to enter, invade and kill the bark and so do greater injury than the mere sunburning. Many of the wood-rotting organisms get in through sunburned injuries.

Control.—Young trees should be protected from sunburning by the use of protectors or whitewash, and the older trunks and branches should always be carefully painted with whitewash whenever there is danger from sunburning.

FROST INJURY

Marked injury to the bark on the trunk and large limbs usually takes place only when the freezing is very severe, although the leaves and sometimes twigs may be killed back on large trees without apparently affecting the thicker bark. The degree of injury depends on various factors, such as age, growth conditions and the conditions following the freeze itself.

Symptoms.—The effects of the severe frost in the bark may manifest themselves either by splitting or loosening, or by the death of the bark in certain areas or in certain portions of the trunk or limbs. The loosening of the bark usually indicates that the cambium has been killed, but this is not always the case. Under some conditions the bark may split and the cambium still be sufficiently alive to build up new tissue even when the bark is separated from the wood. Under some conditions, the bark area immediately around the bud union is especially susceptible. This was true in the freeze of 1894–1895 in Florida. Certain areas, especially those adjacent to the crotches on the large limbs, are often susceptible to frost injury.

Secondary Effects Following Frost.—The injury from frost on the bark may open up the way for the invasion of various disease-producing organisms. For example, after the freeze of 1913 in California, there was considerable injury from the Sclerotinia fungus, which entered the tissue killed by the frost and proceeded farther into the sound tissue of the trunks and limbs. The Botrytis gummosis due to the fungus *Botrytis cinerea* is apparently favored by severe frosts. The frost also renders the wood and bark of lemon trees especially susceptible to a species of Diplodia. This fungus may rapidly invade and discolor the wood of large branches that had been cut off too soon following a freeze.

Resistance to Bark Injury.—The resistance to frost injury of the bark of the trunk and large limbs in the different common commercial varieties of Citrus from highest to lowest appears to be about as follows: Satsuma, sour orange, sweet orange, grapefruit, lemon, lime and citron. This order may differ somewhat for the fruit itself and may vary according to the growth conditions of the tree at the time of the frost. The lemon, lime and citron trees are considered very tender to frost, while orange and grapefruit are fairly resistant and Satsuma oranges are usually the most resistant.

Treatment of Frosted Trees.—The treatment of frosted trees must necessarily vary according to the degree of injury, the age of the tree and other factors. No rigid methods adapted to all cases can be given in the space within the scope of this publication. The following suggestions are based largely on the result of experiments and observations in Florida following the freeze of 1894–1895 (Webber 1895) and in California after the severe freeze of 1913 (Webber *et al* 1919, Culbertson 1922, Blanchard and Hodgson 1923).

Trees should usually be left for a long period after a severe frost before any branches are removed by pruning. Experience has shown that pruning too soon after a severe frost is usually either definitely harmful or an added expense, even when it results in no apparent harm. It is best to wait for a number of months or even a year till new branches become established and the extent of the dying back can be determined by definite markings in the bark and wood.

If the trees have been defoliated, the exposed trunks and large limbs may be protected against sunburning by whitewashing. This may be put on with a brush or with a spray outfit. In moist situations, where there is danger of parasitic fungi entering and progressing into the sound tissue, the exposed wounds may be treated with Bordeaux paste, or strong Bordeaux mixture or copper sulfate may be put into the whitewash at the rate of 3 pounds to 50 gallons of the spray material.

After six months or a year has elapsed and preferably when growth is active, the dead limbs may be pruned out. In making large cuts after frost, especially in sections where wood decays tend to follow, tools should be disinfected frequently and the cuts more than 1 inch in diameter should be treated not with a water-tight covering, but with a good disinfectant, such as Bordeaux paste, mercuric cyanide, mercuric chloride, 10 per cent liquor cresolis compositus or a safe grade of carbolineum (Chap. VI). After disinfecting, these should be left several days to a week, depending on the rapidity of drying, before covering. Then the wound may be painted with asphalt paint, white lead paint, a good grade of grafting wax or other coverings (Chap. VI). In the regions where wood-rotting fungi are prevalent, it is better not to use water-tight coverings at all than to put on such coverings immediately after pruning.

When grafting wax and asphalt paint were applied in this way in the coastal sections following the freeze of 1913 in California, the wood and branches were attacked by wood-decaying fungi much more readily than when nothing at all was applied. For this reason the procedure outlined above of first disinfecting the wound, allowing it to dry thoroughly and then putting on the covering later is advisable. The tree seems to be much more resistant also to the inroads of these fungi during the active growing period than at other seasons of the year; consequently the trees should receive good standard cultural care after a frost. It appears to be a mistake to use a greater amount of fertilizer at such times than under normal conditions.

Rebuilding Frosted Trees.—Experiments and investigations by Blanchard and Hodgson (1923) have indicated that the following methods are useful under southern California conditions:

1. If the outside shell of the foliage is injured, the tree should be left alone for several months or even a year; then it should be cut back just above the best growth but in such a way as to save as much of the foliage as possible.

2. If the top is more severely injured, so that it has died back and contains frost cracks on the main limbs and branches, the pruning should not be done until at least June and July following a winter frost and possibly not until the next spring. The dead wood and branches should be removed and the limbs not too badly injured saved.

3. If injury extends to just below the main limbs, but a large portion of the trunk is still unharmed, after a period of several months, three or four shoots growing out from the trunk should be selected and as few as possible of the others thinned out.

4. If the bark on the trunk is badly split and cracked, but part of it is sound above the bud union, all the shoots may be left growing or a single shoot may be selected later, leaving as many of the others as are not crowding it for one or two years longer before finally cutting them out. This single selected shoot may be topped at the desired height to serve as the new top. Later, one or two years after the frost, and after all the extra shoots have been removed, the trunk may be cut off just above the base of the shoot that is being used for the new top. The cut surface should be thoroughly disinfected, as indicated above, and allowed to dry for three days to a week before putting on a water-tight covering.

5. If the bark of the trunk is injured down to the bud union, even though live strips may exist above, it is best to allow shoots to grow from below the bud union and, after six months or a year has passed, to select the shoot for the new tree. Since this has grown from the original stock, it will need to be rebudded by inserting buds of the desired variety into the main limbs during the second autumn. A crown grafting or budding below the old union, which has proved successful under Florida conditions, is usually less satisfactory in California.

PART III

DISEASES OF BRANCHES, TWIGS AND LEAVES

INTRODUCTION

The diseases on branches, twigs and leaves, considered as to the nature of the lesions or effects, may be arranged in the following classes:

1. The eruptive diseases, in which the tissue is raised, forming scabs, pustules or other prominences composed of modifications of the host tissue, as Citrus canker and scab.

2. The superficial growths or effects, not composed of the host tissues, as sooty mold, lichens and powdery mildew.

3. Diseases in which dead spots or lesions of limited extent are formed, usually with sinking and collapse of tissue, as various leaf spots.

4. Diseases causing extensive death of parts, as Diplodia twig blight and pink disease.

5. Diseases characterized by extensive changes in form or color, or producing other general effects, as knots, galls, warping of leaves and types of chlorosis.

KEY TO DISEASES OF BRANCHES, TWIGS AND LEAVES

PAGE

I. Diseases or effects characterized by pustules, dots, stains, markings or scab-like effects on or within the surface layers or raised above the surface:

A. Raised above the surface in the form of rough or smooth pustules and scab-like prominences not readily rubbed off. Usually arising from changes in the outer cells of the leaf or twig:

1. Affected areas usually elevated on both sides of a leaf, spongy or corky, with greasy margin and usually an encircling yellow halo. Grapefruit especially susceptible—
   Cancrosis or Citrus canker 212
2. Affected areas cream-colored to brownish and even pinkish, more irregular and usually more elevated than the last; on leaves the areas are elevated on one side only and often conical, usually causing distortion of the leaves. Found also on young shoots. Sour orange and lemon especially susceptible—
   Verrucosis or scab 222
3. Pustules small, brown to dark brown, 1/50 to 1/25 inch in diameter or larger. Nearly circular in outline. Smooth on top, breaking around the edges. Often occurring in lines or parts of circles—
   Melanose 226
4. Small pustules or dots of various sizes, sometimes much like the last in general appearance, but smooth and flat on top and usually less elevated than the last and not typically broken around the margins. Sometimes occurring in flat areas of considerable extent—
   Gum spots on leaves 252

PAGE

5. Dark, slightly elevated spots on leaves appearing like a small bit of dark grease under a transparent membrane—
   Greasy spot or black melanose.......... 229
6. A small brown elevated blister on leaves in the center of a circular light-yellow spot; in South Africa—
   Ring blotch.......... 241
7. Spots beginning on twigs six to nine months old and older, oval, ⅙ to ½ inch, slightly raised, reddish brown at first, smooth and glazed on top, later showing longitudinal cracks and finally breaking into small flakes and scales. Often with a darker center surrounded by a reddish-brown band—
   Leprosis or nailhead rust.......... 231
8. Spots much like the last, cinnamon to fawn in color and smooth except in the center where a small, round, grayish, sunken pit occurs. Also surrounded by a sharply defined furrow. In Argentina—
   Lepra explosiva.......... 240
9. Longitudinal lines of excrescences on the terminal stems, mostly near the base in the bark of the fruit spurs, or in the leaf axil among the buds; often accompanied by gum pockets and multiple buds (See also C-1)—
   Exanthema.......... 243

B. Superficial coatings or markings easily rubbed, scraped or washed off, leaving the epidermis apparently intact:

1. Black, sooty, dry, mold-like conditions usually obscuring the surface of leaves—
   Sooty mold.......... 253
2. Light-gray to greenish-gray specks, or larger thin, flat, gray bodies lightly attached to the surface—
   Lichens.......... 260
3. Yellowish-green, powdery growth on surfaces of leaf and twig, easily rubbed off—
   Various green algæ.......... 261
4. Irregular wart-like or flattened star-shaped bodies, black externally, colorless within, 4 to 5 millimeters in diameter; attached to the surface of leaves; West Indies—
   Atichia fungus.......... 262
5. Light-buff felt-like membranes encircling the twigs—
   Septobasidium fungus.......... 257
6. Small raised pustules, spherical or elongated, of various colors, easily scraped off without visibly disturbing the epidermis—
   Scale insects.......... 263
   Entomogenous fungi.......... 266
7. White surface growth in radiating patches—
   Powdery mildew.......... 255

C. Not prominently raised above the surface, nor prominently sunken; resulting from changes in the surface cells of the leaf or twig:

1. A glossy, resinous-like stain on the surface of terminal shoots, chestnut to dark brown in color. Often accompanied by small gum pockets and multiple buds—
   Exanthema.......... 243

Page

2. Tan-colored areas often involving entire surfaces of twigs with exception of thorns, buds and portions near attachment of leaves—
    Lightning injury 315
3. Circular spots on leaves slightly raised, reddish brown when covered with hair-like outgrowths or brownish to greenish brown when these are absent. Often causing enlargement of affected twigs—
    Parasitic alga spot 261
4. Continuous scurfy areas sometimes very slightly raised above the surface or causing slight warping of leaves—
    Thrips injury 506
    Wind chafing 509

II. Definite dead spots or lesions usually limited in extent, usually sunken:

1. Dead areas on margin or tips of young lime leaves, with remaining portion distorted in growth—
    Anthracnose of limes 283
2. Brown circular dead areas on margins, tips or center of leaves nearly or quite mature, often accompanied by black dots—
    Anthracnose leaf spot 290
    Miscellaneous leaf spots 279
3. Light-colored, indefinitely defined, watery-appearing areas turning brown and causing leaves approaching maturity to shed. In Japan—
    Phyllosticta leaf spot 274
4. Dark watery irregular patches turning brown, causing leaves to fall while still green—
    Phytophthora leaf blight 275
5. Irregular brown dead areas on the tip or margins of the leaf blades—
    Alkali injury 318
6. Dead circular spots on leaves preceded by a felt-like brown or chocolate-colored mass of mycelium and spores. Egypt—
    Chocolate spot 276
7. Death of leaves and twigs accompanied by a smoke-gray membrane and whitish to brownish strands of mycelium—
    Thread blight 314
8. Dead areas varying in shape and extent any place on the blade—
    Frost injury 277
    Fumigation injury 279
9. Beginning as pinkish pustules on bark of twigs or branches and developing into an orange-pink encrustation. Bark becoming watery and finally dark brown, dry and shredded. Wood tissues sometimes discolored—
    Rubellosis or pink disease 304

III. Diseases or effects manifested by progressive death of tissue of considerable extent:

A. Death of entire twigs or extensive bark areas on branches:

1. Death of either young or mature twigs and branches, especially on lemon trees, usually at first with softening of bark and later with whitish or light-buff discoloration, and frequently with formation of gum and black seed-like bodies (sclerotia) under the bark, and a shredded condition on weathering—
    Sclerotinia twig blight 310

PAGE

2. Orange-pink encrustations on the bark. Bark becoming watery and finally dark brown, dry and shredded. Mostly in eastern hemisphere—
   Rubellosis or pink disease 304
3. Much like No. 1 at first, but later not so light-colored nor with bark so prominently shredded, and often with gray coating on surface in moist cool weather—
   Botrytis twig blight 311
4. Sudden wilting and death of young shoots on lime trees in Florida and the West Indies, together with blighting of blossoms and young fruit—
   Anthracnose of limes 283
5. Sudden death of individual scattered twigs in California in summer or fall, with a short split in the mature bark and often with copious gumming at a point at a considerable distance from the apex. Usually after a period of hot weather—
   Twig gumming 315
6. Dying back of twigs usually accompanied by staining of terminal portion and frequently with excrescences and small gum pockets and multiple buds—
   Exanthema 243
7. Death of twigs by girdling by progress of lesions arising at or around the leaf petiole, usually in very damp, cool weather followed by medium temperatures; in northern California or Sicily—
   Citrus blast or "mal secco" 293
8. Gradual dying back of mature twigs over an entire tree following indefinite symptoms suggestive of lack of moisture even when moisture is sufficient and when roots are known to be normal and with subsequent production of sprouts from base. Especially on old orange trees and known only locally in Florida and possibly West Indies—
   Citrus blight 312
9. Gradual dying back of mature twigs and branches. Often forming a distinct line of demarkation at certain periods and then dying back again at others. This may be produced by a variety of causes or set of conditions, among which are—
   Anthracnose or withertip 287
   Diplodia twig blight 308
   Effects of Phomopsis 228
   Frost injury 277
   Lack of water, nutrition, etc 292

B. Death of a large part or the entire portions of leaves:

1. Water-soaked brown areas resulting in wilting and abscission of leaves—
   Phyllosticta leaf spot 274
   Phytophthora leaf blight 275
2. Leaf rolling up, and drying and remaining firmly attached with a small reddish-brown lesion surrounding the leaf petiole—
   Blast 293
3. Leaves dead and dry and firmly attached to the branch—
   Frost injury 277
   Fumigation injury 279

Page

IV. Extensive changes in form or in the amount of tissue; often resulting in abnormal growths or misshapen parts:

1. Rounded woody abnormal growths at first covered with nearly normal bark, later becoming fissured and furrowed; wood normal or streaked with black—
   Sphæropsis knot 322
   Galls 326
2. Swollen, thickened shoots with short internodes, irregular, bent and twisted branches with abnormal number of secondary shoots resulting in a thick mass of illshapen twigs—
   Witches'-broom 327
3. Vine-like or shrub-like parasites attached to the bark by root-like projections through which they draw nourishment from the Citrus host. Usually causing swellings or gall-like growths—
   Parasitic flowering plants 341
4. Leaves and young shoots much curled and deformed
   Aphis injury 330
5. Leaves much blistered and pocketed; South Africa—
   Psilla 333
6. Leaves slightly crinkled and warped, often accompanied by rough type of fruit—
   Crinkley leaf 329
7. Leaves misshaped and warped with corky scabs on the wart-like projections (see also I-A-2)—
   Verrucosis or scab 222
8. Leaves misshapen with gray scurfy areas in lines or irregular patches (see also I-C-4).
   Thrips injury 506

V. Absence of normal green color without visible changes in form or structure of leaf:

1. Complete or nearly complete yellowing, spread rather uniformly over entire leaf—
   Chlorosis 334
2. Yellowing in spots between the main lateral veins of the leaf—
   Foliocellosis or mottle leaf 336
3. Yellow rings surrounding a dull-green center, often accompanied by a brown blister; South Africa—
   Ring blotch 241
4. Irregular faded areas on the leaf blade—
   One type of fumigation effects 279

CHAPTER XI

ERUPTIVE DISEASES

CANCROSIS OR CITRUS CANKER

The eradication of this disease in Florida, parts of the other Gulf states and in South Africa, after it had become well established on susceptible varieties and in spite of great difficulties, is perhaps one of the most remarkable achievements in the history of plant-disease control, and has tended to focus more attention on this than on any other Citrus disease.

History and Geographical Distribution.—According to Berger (1914*b*), Citrus canker was first introduced into the United States about 1911 and was first identified as a new disease in 1913. It was not generally recognized as a serious menace until 1914, and its true cause was not discovered till 1915 (Hasse). It appears to have been introduced first on seedling trees of trifoliate orange, *Poncirus trifoliata*, shipped from Japan to Texas, Mississippi, Alabama and Florida, where it spread to other varieties. It was also introduced on Satsuma orange trees shipped direct from Japan. The first indication that Citrus canker was distinct from scab appears to date back only to about 1899, when navel oranges were introduced into Japan. This served to differentiate the two diseases, since navels were subject to canker but were previously known to be resistant to scab. The history of canker in Japan has been discussed by Tanaka (1918*a*).

In Florida, canker developed in shipments of trifoliate orange trees from Texas and also from Satsuma trees direct from Japan and spread to other species and varieties of Citrus. It was at first confused with Citrus scab, but in 1913 was recognized as new. Citrus canker has been investigated by many plant pathologists, among which are Stevens (1914*b*, 1915, 1918*a*), Wolf (1916*a*), Hasse (1915), Doidge (1916, 1918), Peltier (1918, 1920), Peltier and Frederich (1920, 1924, 1925), Lee (1918, 1920, 1921, 1922), Jehle (1916, 1917, 1918) and others.

Citrus canker has not as yet been found in Cuba, Porto Rico, Arizona or California, nor in other parts of the western hemisphere not previously mentioned. In Europe, it has not yet been reported from Spain, Italy or other Mediterranean countries. This disease was at one time well established in the Union of South Africa, apparently spread from shipments of Citrus trees from Japan; it is now almost entirely eliminated according to recent reports, due to effective eradication measures which have been undertaken. It has been recently reported on limes in Mauritius. Of the Pacific islands and countries, Citrus canker occurs commonly in the Hawaiian Islands and the Philippines. In Australia, it has also been found only in the Northern Territory, but eradication measures have been instituted there also. In Asia, the disease has been reported from Ceylon, India, Java, the Malay States, Siam, Indo-China, China, Formosa, and Japan. It is usually believed to be indigenous to China, although in Japan it has also been present for a considerable length of time (Tanaka 1918, (Fig. 56)).

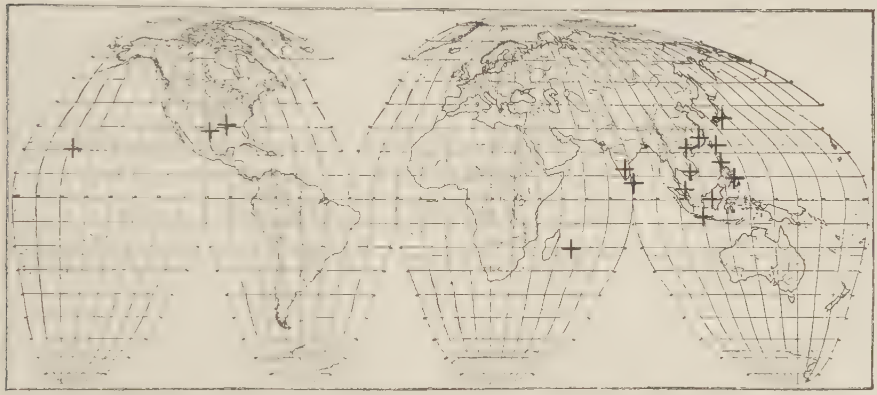

Fig. 56.—Map showing known distribution of Citrus canker.

Susceptibility of Citrus Species and Varieties.—Citrus canker varies in its seriousness on different species and varieties of Citrus, and this feature, together with differences in climatic conditions, makes the disease a most serious one to Citrus production in some countries but a less threatening one in others. The disease is most serious under Florida conditions on the grapefruit, *Citrus maxima* var. *uvacarpa*, and next on the trifoliate orange, *Poncirus trifoliata*, and the limes, *C. aurantifolia* (Berger 1914). Limes, except the Tahiti, are also very susceptible in the Philippines (Lee 1918). The sweet oranges, *C. sinensis*, are next in susceptibility under Florida conditions, although the sweet oranges of Mediterranean origin, such as the Valencia, Jaffa, Ruby and Mediterranean Sweet, appear to be less susceptible than those of the Florida group, such as the Pineapple, Parson Brown and Magnum Bonum. The Washington Navel would be classed in its degree of susceptibility with the sweet oranges of Florida origin. The American-grown lemon varieties, such as the Lisbon, Clarke, Eureka and Thornless, as observed by Lee, are of much the same degree of susceptibility as the sweet oranges of the Mediterranean group. Observations indicate less susceptibility in Florida.

The Unshiu oranges, *C. nobilis* var. *unshiu*, known in the Gulf states as Satsumas, have an even less degree of susceptibility than the lemons, while the mandarin oranges, *C. nobilis* var. *deliciosa*, have a very slight degree of susceptibility and are commercially resistant. An explanation for this resistance of the mandarin oranges as compared to the grapefruit has been offered by McLean (1921*a*) and McLean and Lee (1922) in the fact that the stomatal openings are more narrow and much less subject to water entrance in the mandarin than in the grapefruit (Fig. 57).

The thick-skinned East Indian pummelos, *C. maxima*, in the Philippines are in much the same class of susceptibility as the *C. nobilis* group. The calamondins, *C. mitis*, grown rarely except as dooryard trees, are even more resistant than the mandarin oranges according to both Lee and Peltier. A species known in Japan as *C. yusu*, having little commercial value but possibly of value as a stock or as a parent plant in breeding, is the most resistant Citrus species with which we are familiar; its resistance almost approaches to immunity. The citrons, *C. medica*, are also commercially resistant. There are four species of kumquats; of these, three, *Fortunella crassifolia*, *F. margarita* and *F. japonica*, are cultivated and are highly resistant; the fourth, *F. hindsii*, occurs in China naturally and is not cultivated; it is very susceptible.

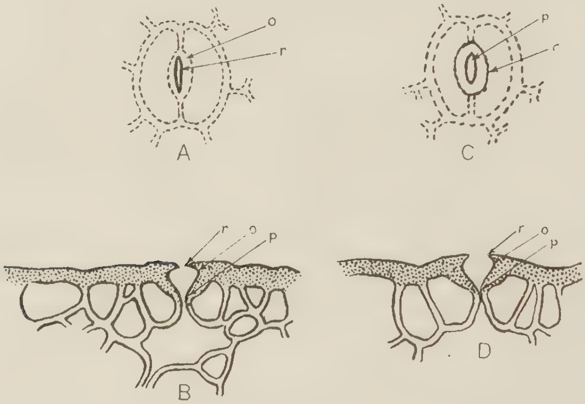

Fig. 57.—Stomata of Citrus leaves. A and B of mandarin orange, *Citrus nobilis;* C and D of grapefruit, *Citrus maxima;* A and C surface view; B and D median cross section, ×570. Showing ridge of entrance, r; outer chamber, o; and pore, p. (*After McLean* (1921).)

All hybrids as summarized by Peltier and Frederich (1920) under Alabama conditions are attacked in varying degrees:

> The citranges, citrumelos, citradias, citrandarins, citrunshus and cicitranges, all having *Poncirus trifoliata* as one parent, are extremely susceptible . . . The citrangedins, citrangarins, citrangumas and citrangequats, with susceptible citranges as one parent, are not only hardy, but decidedly resistant to canker;

in fact, the citrangequat is practically immune in spite of the fact that it is a rapid grower. The limequats and orangequats are somewhat susceptible. Limelos and orangelos are as susceptible as grapefruit, while clemelos, siamelos, satsumelos and tangelos are not so resistant as the mandarin oranges. The calarins and calashus are as resistant as either parent, while siamors and bigaraldins are susceptible.

A more complete account of the susceptibility of commercially grown Citrus species, wild relatives and hybrids is given by Lee (1918, 1920), Peltier (1918), Peltier and Frederich (1920, 1924*a*).

Since the most susceptible Citrus species, the grapefruits, are of especial commercial importance in Florida, where periods of warm, moist weather are frequent, Citrus canker threatened to cause more serious damage there than in the Gulf states where the Satsumas, a more resistant species, were of greater commercial importance. In California, where the grapefruit is not so commercially important and where the rainfall is wanting during months when temperatures are suitable for infection, canker would not be expected to be so serious.

In parts of Japan where Satsumas and pummelos of the East Indian type are the Citrus fruits principally grown, and where the temperatures are considerably lower than in Florida, Citrus canker is not considered serious. In orchards in Japan, where sweet oranges are grown, however, there is a serious blemishing of the fruit, a slight fruit drop and frequently a considerable leaf drop.

Citrus canker is, therefore, of varying commercial importance in the countries producing different classes of Citrus fruits and having different climatic conditions.

Symptoms on Leaves. *Young Lesions.*—On young, vigorous, actively growing leaves, Citrus canker is first apparent to the unaided eye as a small, yellowish spot, about the size of a pinhead (1⁄16 inch in diameter), usually, but not always, visible on the lower surfaces first. A slightly later stage usually shows a small, white, spongy eruption on the lower surface, with the upper surface raised, sometimes smooth but more often ruptured and roughened and of a sponge-like texture. If the canker has developed quickly under extremely favorable conditions, the spongy tissues will be white; if, however, the canker has developed slowly, they will appear tan colored or brown. On the upper surface, the smooth, pinhead appearance commonly ruptures as the lesion progresses, and also becomes spongy or rough. Commonly with such eruptions, a margin appears around the roughened area which has a watery, glazed and greasy appearance, frequently somewhat raised, and yellowish brown or even green in color (Fig. 58).

In three weeks' time on an actively growing leaf, a lesion may be 3 to 4 millimeters in diameter, brown and roughened on both surfaces. In all the developing stages, an area surrounds the main lesion in which the chlorophyll has faded from the leaf tissue. This area frequently has a watery, halo-like appearance and is yellow, shading off into the normal green of the leaf. The halo persists even in very old lesions, as seen in Fig. 58.

Old Lesions.—Old lesions become brown, corky, hard and lignified. The lesions, which are often circular when young, are, in old cases, frequently irregular. The circumference, which may be entire to the naked eye in very young lesions, is more nearly erose in older ones.

The size of the lesion varies with the species of host attacked and with conditions of growth. Lesions are usually larger on grapefruit and pummelo, on which they may be nearly ⅓ inch (8 millimeters) in diameter, and are usually not quite so large on leaves of the sweet oranges. On leaves of the limes and lemons, they are much smaller, frequently not more than ⅛ inch (3 millimeters) in diameter, but with a more pronounced elevation of the affected tissues. The light-brown color characteristic of advanced lesions on grapefruit, sweet-orange, mandarin-orange and trifoliate-orange leaves is darker brown and on those of limes and lemons almost black. On the other hand, cankers on leaves of the mandarin- and Satsuma-orange varieties are less elevated than in either of the preceding cases, but are darker in color than those on the grapefruit or sweet orange, though not so dark as those on the lemon or lime.

How to Identify Citrus Canker.—To identify Citrus canker and distinguish the lesions from other leaf spots, certain rough tests may be used as follows: (1) Citrus canker lesions on leaves will be elevated and readily apparent to the touch on both surfaces, whereas many injuries other than canker are not elevated in the same manner; (2) canker lesions have a glazed margin with an oily appearance surrounding the eruption, a character which is not generally common to other diseased spots on Citrus leaves, but which, together with the yellow halo, is very distinctive; (3) with a hand lens a crater-like appearance may be noted which is sometimes difficult to see with the unaided eye. This crater-like appearance is not visible in all young lesions, but as the lesions become older, the margins are elevated, leaving within the margin a depressed area (Fig. 59).

Diseases with which Citrus canker might be confused are leprosis or nailhead rust, black spot of the Orient and possibly, to one searching for the disease from written descriptions, melanose, tear stain, scab, spine punctures, gum spots on leaves and one type of fumigation injury on fruit. Melanose and gum spots are flat lesions; melanose spots are about the size of a pinhead and lack the rough corky surface of canker lesions. One familiar with melanose and gum spots will not readily confuse them with canker lesions. Canker and scab, which are both enlargements of the tissues, may be more readily confused. Scab, however, appears as a wart-like projection from one side of the leaf,

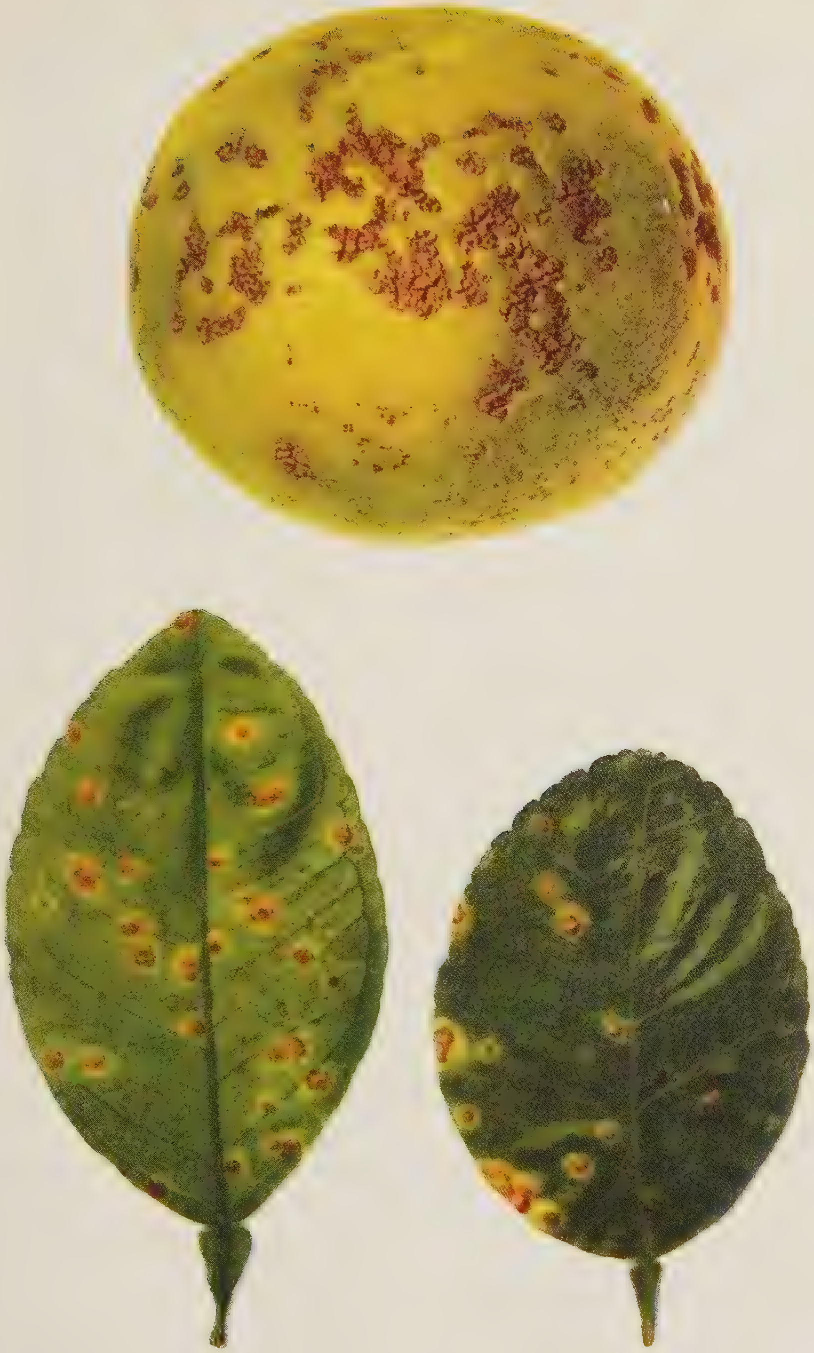

Fig. 58.—Cancrosis or Citrus canker on fruit and leaves of grapefruit.

(*Facing page* 216)

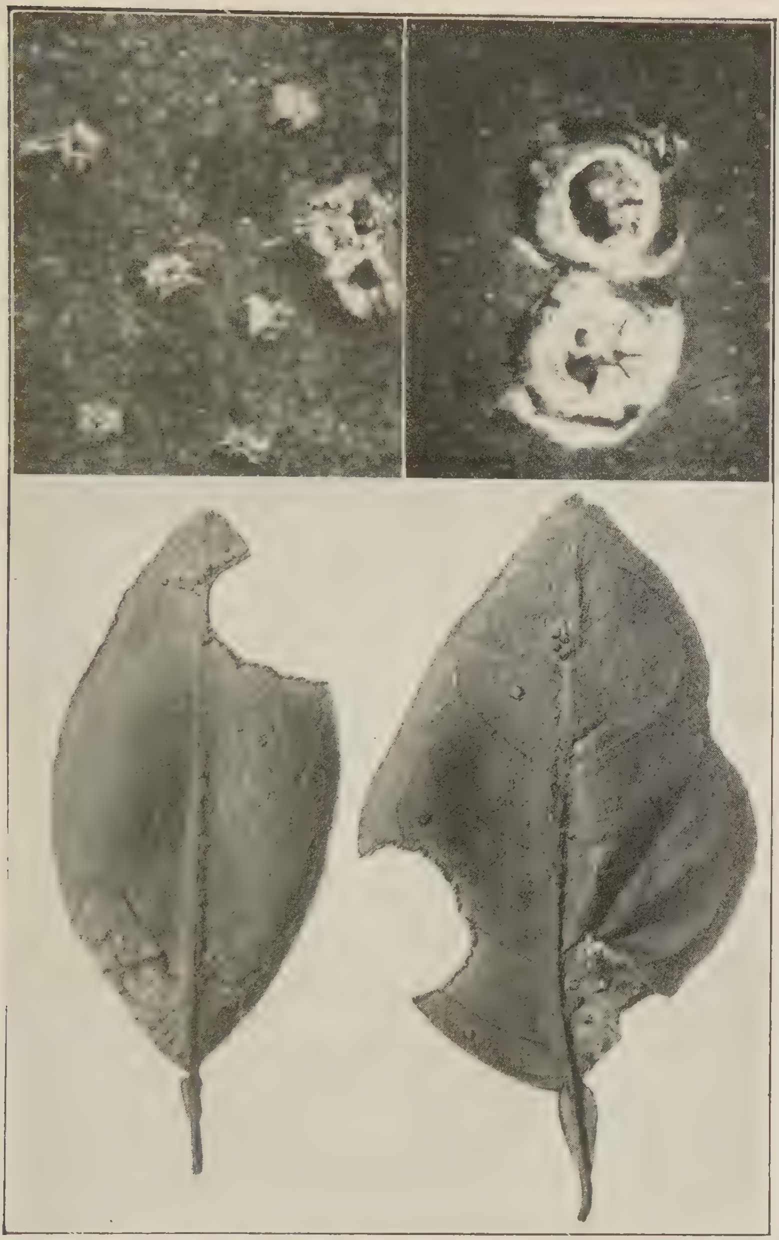

Fig. 59.—Above at left: Photomicrograph showing very young cankers on lime leaves with spongy tissues and torn epidermis. At right, photomicrograph showing crater-like appearance of more mature canker lesions on leaves of sweet orange. Below canker lesions on leaves of Washington navel, natural size, showing also the spread of infection by chewing insects.

usually with distortion and, in older lesions, without the yellow halo. Spine punctures are sunken spots in the tissues and rarely have the halo surrounding them, thus being easily distinguished from Citrus canker. Black spot of Japan and Australia is most common on mandarin-orange fruits, on which Citrus canker is not usually found.

The confusion of Citrus canker with leprosis or nailhead rust is, in many cases, justifiable. Both diseases consist of brown, raised surfaces, and the size of the lesions is frequently the same. Citrus canker lesions are, however, roughened, not glazed, and have the crater-like appearance and the oily-appearing margins previously mentioned, while leprosis has a smooth, although sometimes cracked surface, and lacks the oily margins. Moreover, leprosis is a disease of young twigs and fruits and rarely attacks the leaves; it is more common on the sweet oranges and is entirely absent, or at least rare, on the grapefruit and mandarin oranges, while Citrus canker is serious on grapefruits and is equally as common on leaves as on fruits and twigs. On young, rapidly developing Valencia oranges, as shown in Fig. 198, certain effects of fumigation with hydrocyanic acid gas may sometimes closely imitate canker lesions.

Canker on the Twigs, Branches and Roots.—Lesions on the twigs are common on the more susceptible hosts, such as the grapefruit, lime, sweet-orange and trifoliate-orange varieties. They are rare upon the Satsuma- and mandarin-orange varieties, mature trees of the lemon varieties, or the citrons or calamondins. Once familiar with the lesions upon the foliage, recognition of the disease on twigs follows readily.

Cankers have been found on the bark of mature, lignified branches as large as 6 inches (15 centimeters) in diameter, and branches 2 to 3 inches (5 and 7.5 centimeters) in diameter are quite commonly infected. Stevens (1915) has also mentioned having observed such cankers. Mature-wood cankers have been found upon only the most susceptible hosts, such as the West Indian limes and American-grown grapefruits and, more rarely, on the sweet-orange varieties of Florida origin.

Underground roots of Citrus trees have been repeatedly inoculated, with positive results, although canker has never been observed, occurring naturally upon underground roots of Citrus trees. Examinations have been made repeatedly by digging up badly diseased trees in heavily infected orchards and inspecting the washed roots. This susceptibility of the roots with rare actual infection in nature is perhaps logical since the organism is quickly killed out in orchard soils, and thus natural infection of uninjured underground roots would be apparently difficult. Nevertheless, it is conceivable that, on roots of very susceptible hosts exposed above the surface of the ground, canker could easily develop at wounds or abrasions and thus be a source of reinfection easily overlooked.

Individual canker lesions have much the same appearance on the fruits as on the leaves, except that the yellow halo is usually absent and the crater-like appearance is usually more noticeable (see p. 482 under Fruit Diseases).

The Causal Organism.—In the early stages of the first outbreak of the disease in Florida, a fungus was ascribed as the cause, but later work proved that a bacterial organism was responsible for the disease. Clara H. Hasse (1915) of the U. S. Department of Agriculture first isolated this organism in pure cultures and reproduced the disease experimentally at will by inoculation. She described the organism as *Pseudomonas citri.*[1]

The organism may be readily isolated from Citrus canker lesions in the usual laboratory peptone-beef-agar dilution plates. On such plates, the organism forms wax-yellow, round, glistening, smooth, convex to pulvinate surface colonies. Buried colonies are biconvex to oval or almost globular. The organism is a short rod with rounded ends measuring 1.56 to 2.97 by 0.45 to 1.47μ. Capsules and a single polar flagellum can be demonstrated from smears direct from a leaf or fruit lesion or from cultures (Fig. 60).

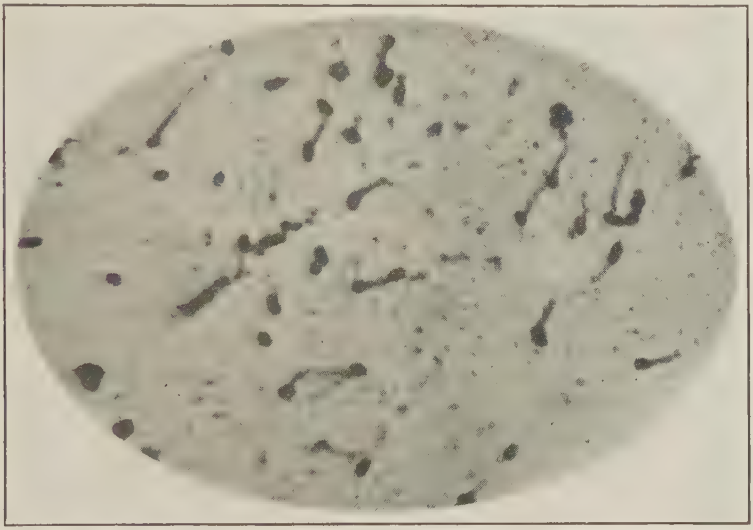

Fig. 60.—The Citrus canker organism stained to show flagella when seen under the microscope. Magnified about 900 diameters.

In culture media, the organism liquefies Loeffler's blood serum and nutrient gelatine, coagulates and subsequently peptonizes milk, reduces methylene blue in milk, produces hydrogen sulfide, forms neither gas nor acid in the presence of sugars, produces ammonia, does not reduce nitrates nor form indol and is strictly aerobic. The most ready test of the organism in culture media is the characteristic growth on potato cylinders; growth is convex to pulvinate, at first empire yellow, then becoming wax yellow or primuline yellow. The medium is reacted upon by diastasic products of the organism to form a white halo or margin upon the growth in from two to four days after the inoculation of the potato. This halo formation and characteristic color on potato cylinders is a very good diagnostic test for the organism. The reproduction of canker lesions on young grapefruit leaves in from five to ten days is, of course, the most reliable diagnostic test.

---

[1] According to the Committee on Nomenclature of the Society of American Bacteriologists, this generic name is used for another group of bacteria and the correct binomial at the present time would be considered *Phytomonas citri.*

Effect of Environmental Factors on the Organism.—The Citrus canker organism is somewhat resistant to drying and requires about 120 days to be killed by ordinary laboratory atmospheric conditions. Exposures of 2 minutes to direct sunlight kill the organism completely, and exposures of 1 minute reduce the numbers very materially. The organism is killed by holding at 125.6°F. (52°C.) for 10 minutes. Freezing for 24 hours has little or no killing or inhibiting effect on the organism. Peltier (1920) has shown that the optimum temperature for growth is between about 68 and 86°F. (20 and 30°C.); the minimum temperature for growth is 41°F. (5°C.) and the maximum 95°F. (35°C.). The minimum temperature for infection during the time employed by Peltier was 20°C., and the optimum temperature for infection lay between 20 and 30°C. It has been shown by Lee (1920) and by Fulton (1920) that the canker organism in orchard soils cannot compete with the normal soil organisms and is quickly killed out.

Tests upon the action of disinfectants on the organism of Citrus canker showed that mercuric bichloride at a dilution of 1 to 20,000; *liquor cresolis compositus*, 1 to 3000; formaldehyde, 1 to 20; lime-sulfur solution, 1 to 1000; copper sulfate, 1 to 200; and quicklime, 1 to 1000, all have a prompt bactericidal action on the organism in the absence of organic compounds (Jehle 1918, Lee 1920*b*).

Effect of Environmental Factors on the Disease.—Citrus canker, like many other diseases, is dependent on a set of environmental conditions, of which temperature and moisture appear to be among the most important. It was found in tests by Peltier (1920) that the conditions essential for infection of leaves were temperatures between 68 and 95°F. (20 to 30°C.) with an optimum temperature of about 86°F., free moisture for twenty minutes or more on the surface of rapidly growing tissue. Lee (1922) has also shown that young newly formed tissues are much more susceptible than older well-matured tissues, and that with most Citrus species, as the foliage and fruits approach maturity, they are almost entirely resistant. It has also been shown that young trees are much more susceptible than old trees.

A study by Peltier and Frederich (1925), of the effects of weather on the world distribution of canker in the light of the above results has led to the conclusion that with a given variety the seasonal distribution of rainfall is the most important factor in the development of Citrus canker. In any country where there is a well-distributed rainfall during a period when the mean temperature is 68°F. or above during a number of months, Citrus canker when once introduced would thrive. It would be most severe during periods about 80°F. or above; if, on the other hand, precipitation is lacking during such temperature, the condition would be unsuitable for Citrus canker.

Prevention.—The fact is now fully appreciated in most countries that the introduction and spread of Citrus canker, as well as certain other diseases, could have been prevented by strict plant-quarantine measures. Countries where canker does not occur, as well as those in which it has been eradicated, are now using such methods to prevent further introduction and spread.

In those countries where Citrus canker newly breaks out but has not become thoroughly spread, eradication methods coupled with strict quarantine of infected areas is the most effective and probably least expensive means of control. In such eradication measures, the destruction of affected trees by burning, quarantine of infected properties and careful disinfection of hats, clothing, shoes and tools of inspectors or others who may have come in contact with infected trees or materials is essential. Since domestic animals are capable of spreading infection, they should be excluded from an infected orchard. For disinfection, mercuric bichloride, 1 to 1000 in water, is entirely safe, and a petroleum blow torch is the most effective method for destroying infected trees. In Florida, during the canker-eradication campaign, inspectors or other individuals whose work brought them in proximity to infected premises wore overalls, tennis shoes and light cloth hats, all of which could be removed and immersed in disinfectants on leaving the premises. Such precautions are essential in the eradication of a highly infectious disease, such as Citrus canker.

In regions where very susceptible varieties are grown, experience in Florida and South Africa has shown the failure of any methods, short of complete destruction of the trees, to control or to prevent the spread of canker.

In some countries where climatic conditions favor canker development and where eradication is not now feasible, such as the Philippines, Java, India or South China, Lee's observations indicate that resistant species and varieties can minimize or largely obviate losses from the disease. Among the grapefruits, the Triumph has a slightly less degree of susceptibility than the other commercially grown varieties. Most of the East Indian pummelos are not seriously susceptible in the Orient. Of the limes, the Tahiti lime is commercially resistant, and for lime substitutes there are resistant species and varieties, such as the calamondin, *Citrus mitis*, the sour orange, *C. aurantium*, and some of the cabuyao varieties, *C. hystrix*. Of the sweet oranges, those of Mediterranean origin can be grown in the Orient, without severe losses from canker; these include the Valencia, Jaffa, Paper Rind, Majorca, Ruby and Mediterranean Sweet.

There are two seedless mandarin oranges grown in Swatow, China, which could be substituted for the sweet orange.

In countries where the disease has become universally distributed, or where the economic or commercial conditions are such that eradication cannot be attempted, the severe effects can be somewhat minimized by a number of horticultural practices. Lee's experiments in the Orient indicate that the use of windbreaks of trees, which prevent the dissemination of the causal organism by the wind and prevent whipping of the foliage, is of great assistance. In some countries, new foliage growth may be stimulated during dry periods unfavorable to canker infection, thereby escaping some infection. Discretion in the use of fertilizers and pruning may be helpful in bringing about the greatest growth, in the dry rather than in the wet periods. Pruning out infected twigs and foliage during the winter or dry seasons to eliminate the sources of infection during periods favorable for canker dissemination has also been shown to be very valuable in the Orient. The control of chewing insects and leaf miners which spread the disease also aids in lessening Citrus-canker development.

Spray applications, such as lime sulfur and Bordeaux 4-4-50 mixture, have been shown to lessen materially canker infection in Japan and the Philippines. Bordeaux mixture with an excess of lime is superior to the so called neutral Bordeaux mixture (Lee and Shino 1922). Since the injury to the fruits is the most serious commercially, spraying should be directed primarily to the protection of the young fruits. Since fruits increase in resistance as they mature, spraying is most effective during the first three months after the fruits are formed.

Treatment of Citrus canker by spraying, however, is an expensive operation, which must be repeated year after year. Consequently, in countries where the disease does not yet occur, the entire exclusion by effective quarantine measures or the prompt eradication of the disease as soon as it appears is the method to be recommended above all others. Where the disease is already established, the growing of resistant species and varieties should also be recommended as preferable to the repeated spraying of the more susceptible varieties year after year.

VERRUCOSIS OR SCAB

Since the details regarding the history, distribution, causal fungus, contributing conditions and control of scab are given on page 485 under Fruit Diseases, the symptoms on leaves and twigs only will be presented here.

Symptoms on Leaves.—Verrucosis is characterized by circular to irregular scabby and wart-like projections. The leaves of susceptible varieties become distorted, misshapen and stunted from the presence of the disease (Fig. 61). The spots frequently become depressed on one side and raised on the other (Fig. 62). The spots, if numerous, may grow together as they enlarge, forming large irregular corky scabs. Unless the attack is unusually severe, the leaves do not drop off.

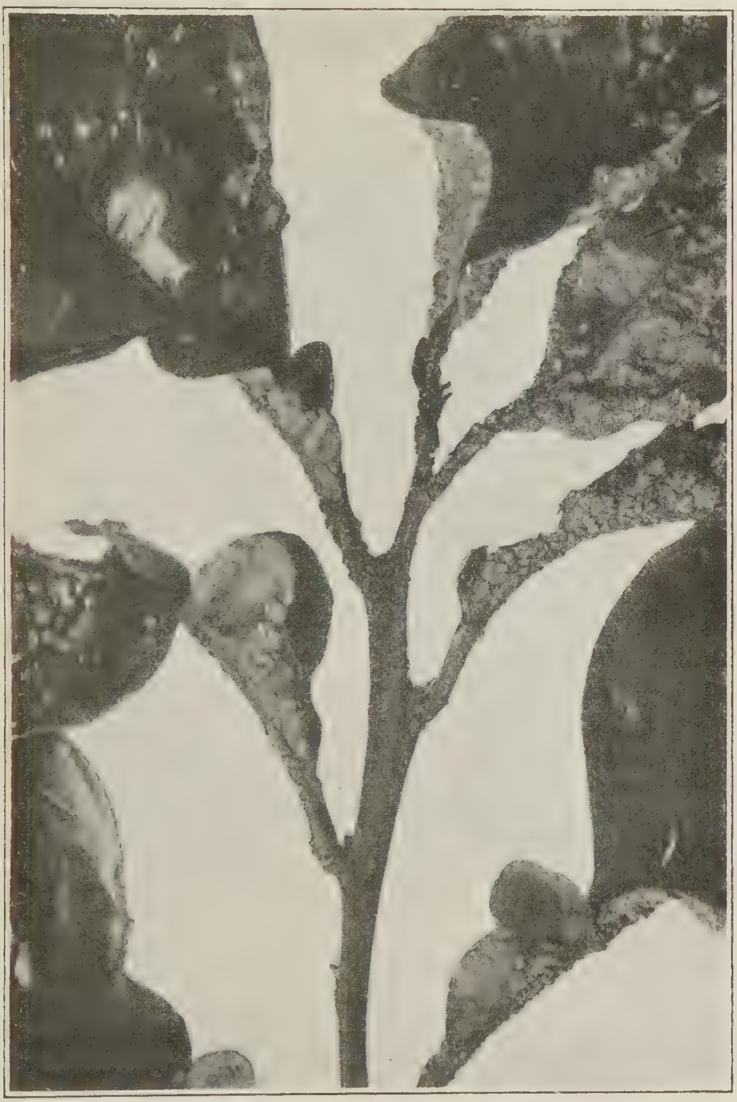

FIG. 61.—Verrucosis or scab on sour orange leaves and shoot.

If the development of the lesions is studied from their earliest appearance on the leaf, they become evident on the very young leaves,[1] before they have unfolded, as small semitranslucent dots soon becoming sharply defined papillary elevations, flat or somewhat depressed at the center. The color of the lesions is considerably varied; at first, various bright colors are exhibited, often in the same lesion; as the leaves age, the color becomes dull and inconspicuous. Young lesions are often salmon buff or flesh ocher[1] (Ridgway 1912). The central areas of slightly older lesions are drab, due to the formation of tiny tufts—the conidiophores and spores of the pathogene. Somewhat older lesions may range from vinaceous-drab to drab, or dark olive gray, with a fine velvety surface formed by the fruiting structures of the causal fungus. This growth may be present for a considerable length of time, gradually disappearing as the leaf ages. On old lesions on grapefruit, it often remains pinkish or rose colored, presenting a smooth, scarred appearance. With the hardening of the leaf, the lesions enlarge, becoming rough, corky, wart-like, occasionally disintegrating to some extent; they are then tan or dull colored and pre-

---

[1] The description of the disease on the leaves was contributed by Anna E. Jenkins of the Bureau of Plant Industry, U. S. Department of Agriculture.

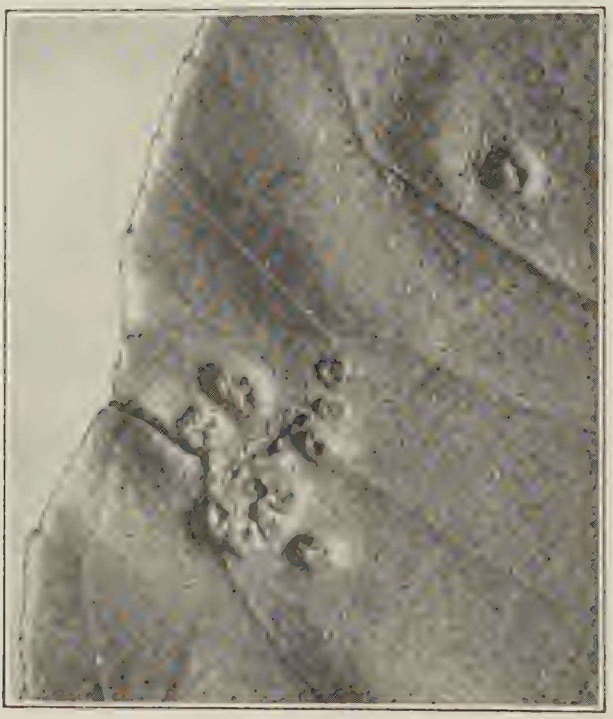

FIG. 62.—Scab lesions on sour orange leaf, about twice natural size.

---

[1] The color determinations were made from fresh leaves of grapefruit, lemon and sour orange, at Orlando, Fla., by F. R. Cole, Bureau of Entomology, and A. E. Jenkins, Bureau of Plant Industry, U. S. Department of Agriculture during the spring of 1925.

sent an unsightly appearance due to the accumulation of dust and the growth of saprophytic fungi over their surfaces.

The lesions occur on either surface of the leaf, particularly on the underside, where they are more numerous. They may be single or irregularly grouped; occasionally they are arranged in a small ring or they may be confluent, forming a more or less extensive and somewhat thickened region. In confluent lesions, the individual lesions may remain distinct each with its drab center, composed of fungus growth as described above, or they may appear as a continuous velvety layer. The lesions may not be visible on the opposite side of the leaf or may penetrate it. On succulent leaves, the tissue in the region of confluent lesions, particularly, is sometimes definitely necrotic. On these brown areas, the lesions show no bright hues but are indicated by the fine velvety growth made up of conidiophores and great numbers of spores. The dead tissue

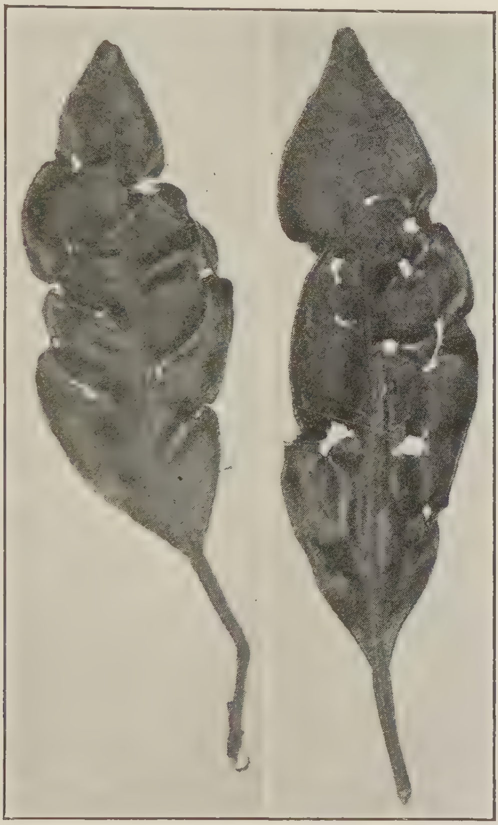

FIG. 63.—Leaves of Satsuma showing the shot-hole effect produced by Citrus scab. Photograph of fresh specimen received from O. F. E. Winberg, Silver Hill, Ala., June, 1925. Natural size. *(Photograph contributed by A. E. Jenkins.)*

soon breaks away, leaving irregular openings or broken leaf margins. On leaves of Satsuma, necrotic areas are rather common, the cracking and breaking away of the dead parts giving a ragged shot-hole effect, as shown in Fig. 63.

Distorted, wrinkled, drawn or stunted leaves are also characteristic evidences of the disease. The deformations often consist of crater-like elevations or hollow conical outgrowths bearing lesions at their apices. In the region of the scab lesions, the leaf may be noticeably etiolated, gradually assuming normal color as the leaves age and harden. The discolorations may be nearly white at first, but later the upper surface exhibits bright-green color, as oil yellow, which shades to the natural leaf color. A grapefruit leaf examined showed vivid green discolorations flecked with apricot-orange dots; on the undersurface were confluent lesions of vinaceous cinnamon and vinaceous drab. Young diseased leaves about to fall may be considerably blanched.

Symptoms on Twigs.—Scab affects the twigs usually on only the most susceptible varieties and on very succulent growth, such as rapidly growing nursery stock (Winston 1923). The lesions arise on such growth as small slightly raised warts with much the same general appearance as on the leaves or fruit (Fig. 61). These lesions with age take on a dusky color.

The control measures are given on page 495, under Fruit Diseases.

MELANOSE

Melanose is characterized by small superficial eruptions or pustules on the surface of young leaves, shoots and fruits. It is now known to be due to the same fungus, *Phomopsis citri*, as that causing stem-end rot (p. 401). Melanose on the fruit is discussed on page 496.

History and Distribution.—The disease was first noticed at Citra, Fla., about 1892 and was first described and named by Swingle and Webber (1896), who believed that it was of recent introduction and was spreading rapidly in the region about Citra. At that date, it was found to some extent at Ocala, Stanton and Sanford. The total damage for the whole of Florida produced by the disease was reported at that time to be slight. Since then, the disease has become one of the most important in middle Florida. It has been found distributed over all Florida and the Gulf states and has also been reported in a number of other Citrus-growing countries, Mexico, Brazil, some of the West Indian islands, Japan, China, Australia, New Zealand, Algeria and probably Egypt and South Africa.[1] It is rarely found in Cuba. (Fig. 64) A marking on leaves and fruit of infrequent occurrence somewhat resembling melanose has been seen in California, but is thought to be due to another related organism *Phomopsis californica* (p. 406). The relation of melanose to the fungus *P. citri* was first shown by Stevens (1912), who produced the disease in numerous experiments with spores from pure cultures of the fungus.

---

[1] H. J. Webber (1925) has recently observed melanose on the east coast of South Africa.

In general, the greatest degree of injury from melanose in Florida from year to year appears to be in a band or zone through the middle part of the Florida peninsula, the injury decreasing toward the south and toward the north. It is suspected that some set of climatic conditions influencing the delicate balance and interaction between host and parasite may be responsible for this fact. Variations from the average conditions would, of course, be expected to change this relative degree of distribution somewhat. It is an interesting observation that, in general, throughout a period of years, the greatest intensity of the disease appears to be located in a central zone between about 27½ and 29½° N. latitude in Florida (Fawcett 1917).

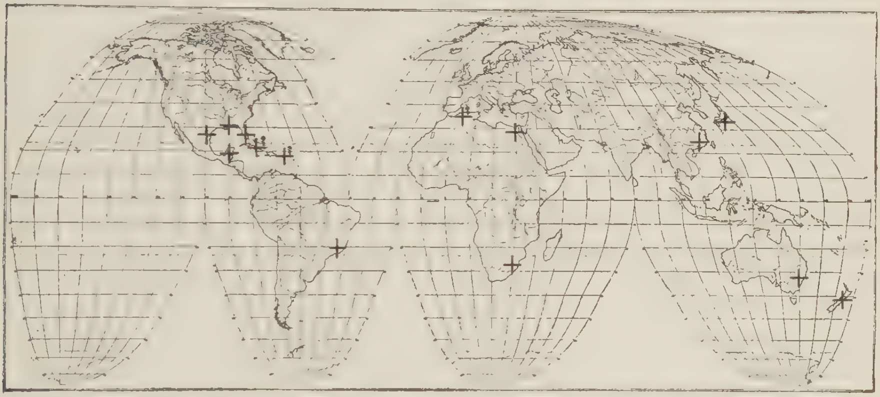

FIG. 64.—Map showing known distribution of melanose.

Symptoms.—The characteristic markings on leaves, stems or fruit are clearly described by Floyd and Stevens (1912) as "raised areas of brown gum-filled cells forming dots, lines, curves, rings and irregular-shaped spots." These individual dots or areas may vary in size but may be $\frac{1}{50}$ to $\frac{1}{25}$ inch (0.5 to 1 millimeter) in diameter. The markings have a wax-like appearance and have various shades of yellow, brown or even black. They may take on the different shades indicated by Ridgway's (1912) hazel, amber brown, tawny, chestnut brown, Kaiser brown and burnt sienna. The dots also suggest drops of partly "burnt sugar," except that the sheen is dull instead of glossy.

Course of Development of Melanose.—The development of the melanose markings has been carefully studied by Floyd and Stevens (1912). In some manner, the fungus, *Phomopsis citri*, brings about an injury to the epidermal and subepidermal cells. A few cells are killed and become filled with a homogeneous hard gum-like substance which gives the color to the spots. It is unlike pure Citrus gum in being insoluble in water, and according to Floyd and Stevens is probably a product of the protoplasm. They found that in early stages the protoplasm is apparently in an active condition with the nucleus evident, but in later stages it is dead.

The shrinking of the cells produces a slight depression in the early stages, but in later stages the injured cells become raised by the development of corky tissue beneath. The tissue involved in the markings are seldom more than five or six cell layers below the epidermis, and the direct injury, therefore, is confined to the epidermal and subepidermal tissues.

Melanose-like Spots.—A spot on leaves somewhat similar to melanose may result as an effect of spraying with Bordeaux mixture. This is frequently known as stellate melanose. As described by Stevenson (1918) on grapefruit leaves, the markings occur on either side of the leaf, though more commonly on the upper side. The spots are usually larger than the individual melanose spots, often being 4 to 8 millimeters across and irregular to stellate in form. They usually possess longitudinal splits through the stellate extensions of the spot. This has also been noted in Florida.

Another marking which is somewhat similar to the true melanose spots may be produced on tender growing leaves when they are sprayed with nicotine sulfate. These are raised, dark brown to black, and may be 0.5 to 1 millimeter in diameter.

Causal Agent.—Melanose is due to the attack of the fungus *Phomopsis citri*, the same organism that produces one of the stem-end rots of mature or nearly mature Citrus fruits. The fungus is found commonly on dead twigs or dead bark of Citrus trees in Florida. The spurs from which infected fruit has dropped frequently die back a distance of 3 to 12 inches or more and often show small drops of gum near the junction of dead and live wood. The fruiting bodies (pycnidia) may be found on dead twigs as very minute black, flask-shaped bodies partially buried in the surface tissue with their rounded tops breaking through the epidermis. In moist weather at certain times of the year, yellowish globular masses of spores ooze out through openings in the top (ostiole) from these pycnidia. The fungus is described on page 404.

Contributing Conditions.—Some of the contributing conditions for the infection and development of melanose are age of tissue, moisture, temperature and presence of dead twigs in the tree. Only young tissue is susceptible to melanose. It has been determined by Burger (1923) that four to six weeks after the petals fall, the tissues of the leaves and fruit become immune to the development of the disease. A certain amount of moisture must also be present at this susceptible period. This may be furnished by heavy fogs, dew or rain. The individual marking may develop in about four to seven days after the spores are placed in moisture on the susceptible tissue. Temperature within certain limits is also probably an important factor, along with susceptible tissue and moisture. The temperature relation of the fungus itself on certain media has been determined by Fawcett (1921*a*). The increase in temperature has a marked effect on an increased rate of mycelial growth up to about 75 to 81°F. (24 to 27°C.) close to the optimum temperature, but temperatures above this retard its growth markedly, no growth taking place at or above about 95°F. (35°C.).

The presence of twigs and branches is also an important contributing condition for the occurrence of melanose. As has been previously mentioned, these may contain innumerable fruiting bodies (pycnidia) from which the spores ooze out in moist weather and get upon the twigs leaves and fruit. Birds and insects acting as carriers may also be contributing factors to the spread of the fungus from tree to tree and from place to place. Winds, especially heavy driving winds with or following rains, are also likely to be important factors in distribution of spores.

Control of Melanose.—Any control for melanose must look toward the prevention of infection by the fungus, since there is no means of eliminating the markings after they have started to develop. The markings may begin to develop under Florida conditions in about three to seven days after the spores are placed upon young leaves. Burger (1923) has shown that leaves and fruit four to six weeks old were immune to the disease even when subjected to abundant sources of infection in the laboratory. According to recent experience based on inoculation and spraying experiments in Florida, thorough spraying with Bordeaux-oil emulsion (3-3-50 plus 1 per cent of oil) ten to twenty days after the bloom has dropped will materially prevent injury from melanose. The details as to spraying for this disease are discussed on page 499 under Fruit Diseases.

GREASY SPOT

Greasy spot, also known as "black melanose" of leaves, has been reported in Florida, Cuba, the West Indies, Japan, China, the Philippines and Java. It should not be confused with the true melanose. Fawcett (1915*a*) observed it especially on grapefruit leaves and believed that its prevalence and effect increased as one passed from the northern to the southern parts of Florida and into Cuba and the Isle of Pines. It was mentioned by Earle and Rogers (1915), Stevens (1918*a*), Nowell (1923) and others. In the Philippines, it is very common on the calamondin, *Citrus mitis*, and in Japan on the *Ko mikan*, a mandarin orange, *C. nobilis* var. *deliciosa*. On this host, according to Japanese investigators, it has been at times a noticeable trouble, causing partial defoliation of trees. While severe spotting of this kind may cause some injury, the disease has usually been considered a minor one.

Symptoms.—Greasy spot or black melanose is especially common on grapefruit leaves, although it is frequently found on other varieties. It is usually located on the under side of the leaf and does not appear to effect the chlorophyll to any extent. The spots have a dark, slightly raised, greasy appearance, suggestive of a mass of dark grease under a semi-transparent epidermis. The spots appear to develop after the leaf tissue is mature and in this respect differ from the true melanose. It has been noted only on leaves and not on the twigs or fruit (Fig. 65).

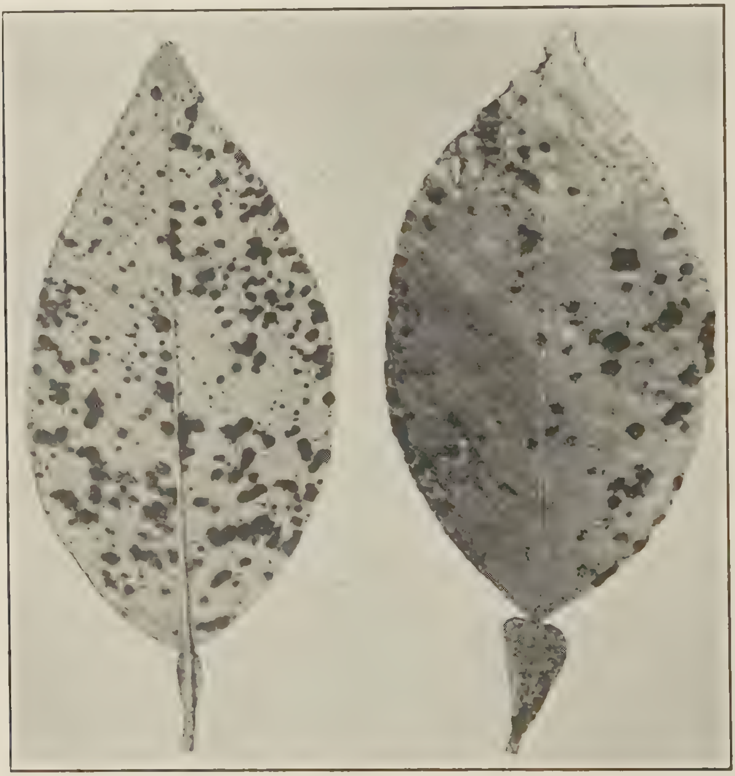

Fig. 65.—Greasy spot or black melanose of unknown cause. (*After Stevens* (1918).)

Possible Cause and Control.—The cause of greasy spot is not known. It has been considered by some experienced growers as a sign of faulty nutrition. Leaves affected with greasy spot are the first to fall when the tree receives a shock of any kind that tends to put it out of condition. There is a possibility that some organism is a factor in originating these spots, though none has been commonly found associated with them.

So far as known, no sufficiently scientific study of this disease has been made to justify a definite opinion as to its true nature. Greasy spot is not considered of sufficient importance to require the employment of control measures, except in so far as its occurrence in abundance may suggest the employment of means to correct faulty nutritional conditions. In Japan, growers are of the opinion that one application of Bordeaux mixture in June, after the flush of new foliage growth has formed, very greatly lessens the trouble.

LEPROSIS OR NAILHEAD RUST

This disease is commonly known in Florida under the name of "nailhead rust" and "scaly bark." The term "scaly bark" has also been used unfortunately by California growers for an entirely different disease, psorosis (p. 158), which has some of the same general characteristics in its later stages. To avoid confusion, therefore, in published accounts other than those to be read locally, the term "leprosis" should be employed for the Florida scaly bark or nailhead rust and psorosis for the California scaly bark. Leprosis is confined almost entirely to the sweet orange, *Citrus sinensis.* Other varieties of Citrus fruits seem to be only rarely or slightly affected, even when growing in close proximity to badly diseased sweet-orange trees.

Distribution and History.—Leprosis was known until quite recently to occur only in Florida. More recently it has been observed by Lee to occur very commonly, although not seriously, in southern China and the Philippines. A disease described by Spegazzini (1921) as lepra explosiva occurring in Paraguay and Argentina appears to have some of the same characteristics as leprosis but is thought to be distinct (p. 240). In Florida, leprosis is confined for the most part to a territory between about 27 and 29 degrees north latitude. Even within that territory it is found in only part of the orchards and is known to have spread very slowly (Fawcett 1911*b*). It is found most commonly in Pinellas County. In recent years, with the careful inspection of orchards under the Florida State Plant Board, the distribution of the disease has been carefully mapped (Fig. 66).

The history of the probable origin of leprosis in Florida, as learned from the older growers in Pinellas County (Fawcett 1911*b*), is as follows: The disease had been known in that part of the state as far back as 1860 to 1870, but the damage was said to have been slight until a few years previous to 1906. About the year 1840, Odette Phillippi, a Frenchman of royal blood, came from Key West, Fla., and settled with a small company of other Frenchmen near the large Indian shell mound at the inner edge of Safety Harbor, on what is known as Old Tampa Bay. Phillippi brought orange and grapefruit seeds with him and planted the grove, owned in 1910 by Mr. Phillippi's grandson, D. J. Booth. It was in one of these original seedling trees, after it had become some twenty years old, that the disease was first noticed. The disease is reported to have spread very slowly and almost imperceptibly over the entire grove of several acres. Contiguous to the grove, Mr. Phillippi grew nursery stock for many years, and many of the old seedling groves of the surrounding country were set out with trees from this nursery. All of these old groves that could be traced back to the Phillippi nursery were found to be badly affected with leprosis. These observations strongly indicate that the disease, as far as Florida is concerned, originated at Phillippi's place and spread from his nursery.

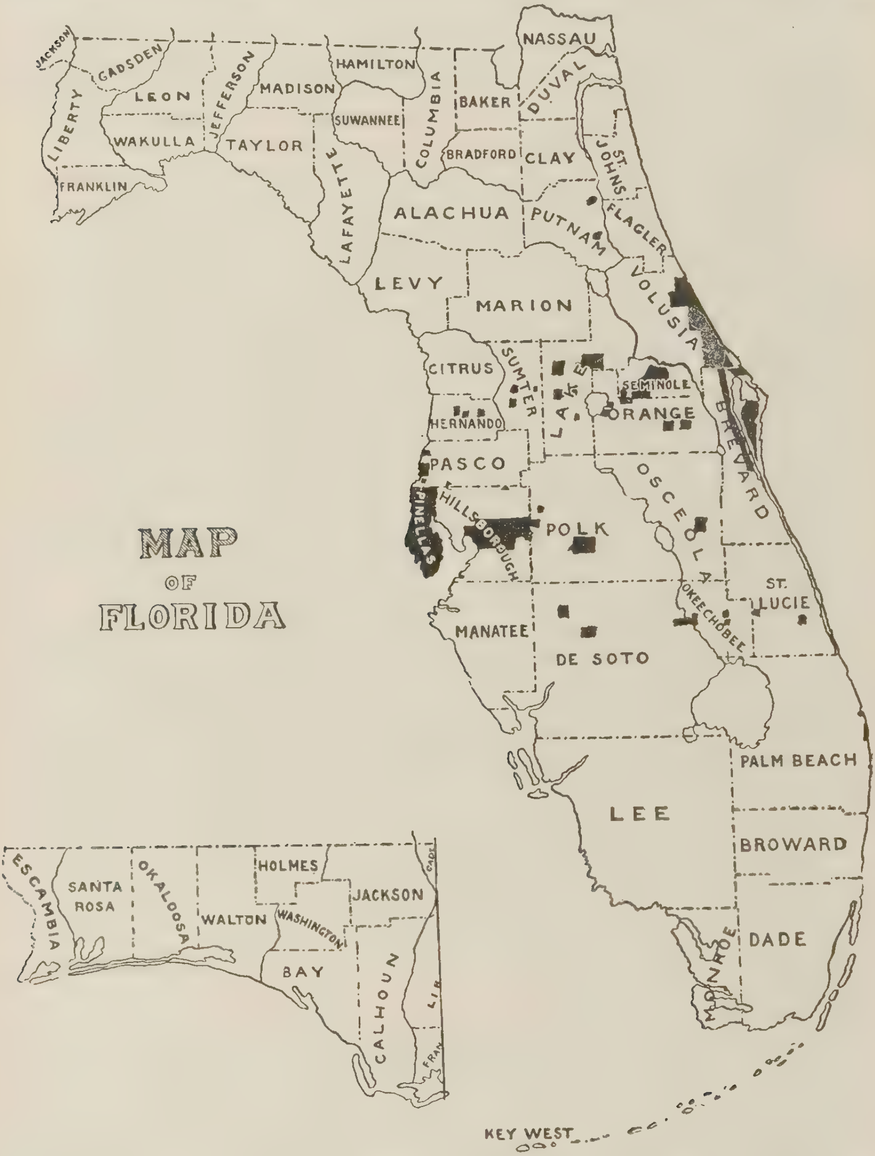

FIG. 66.—Known distribution of leprosis or nail head rust in Florida in 1925. Dark areas show locations of the disease. (*Contributed by F. M. O'Byrne, Plant Board of Florida.*)

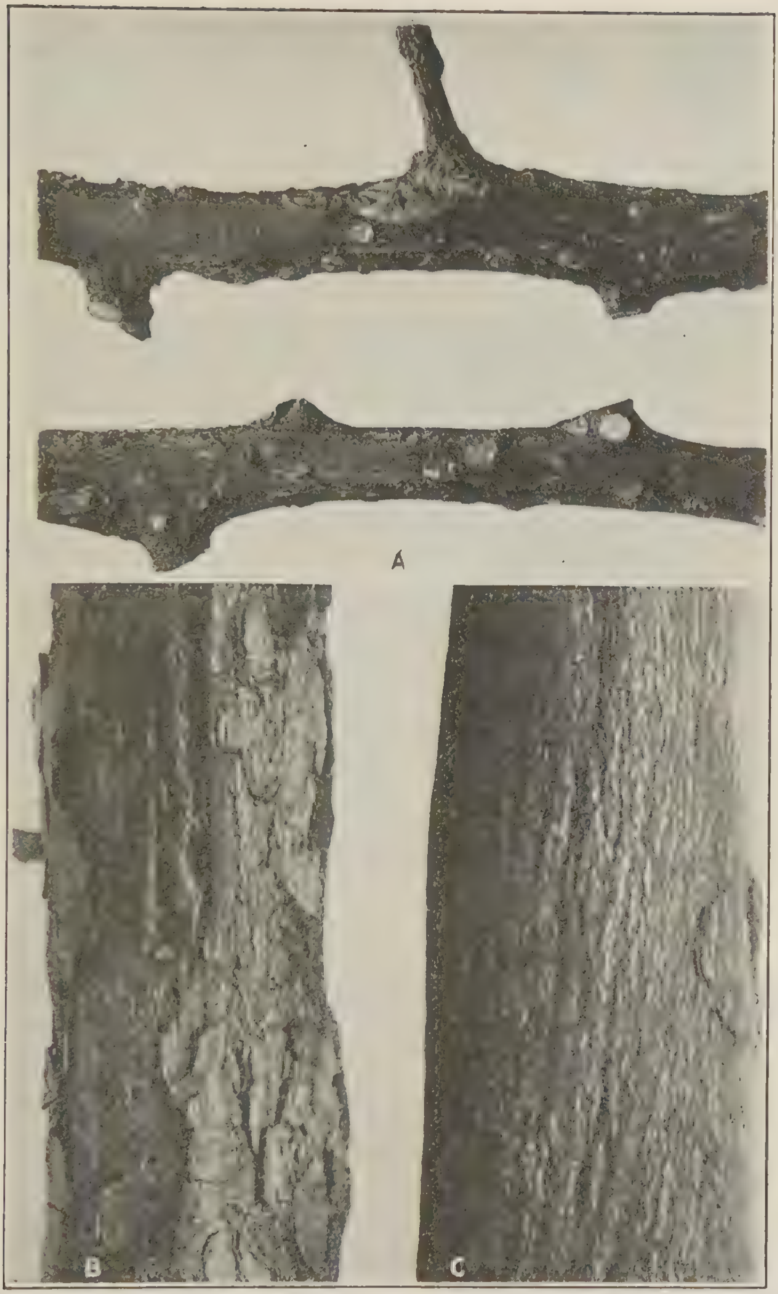

FIG. 67.—Leprosis or nail-head rust spots; A, small raised spots on twigs (see also Fig. 38). B, condition on older branch due to coalescing of numerous spots; C, branch protected by spraying showing one spot near right margin.

In the report of the Florida State Horticultural Society for 1892, A. L. Duncan gave the following account of this grove: "On the western side of the entrance to Safety Harbor in Hillsboro County lies what is known as the Phillippi Hammock. It is a spot of rare natural beauty . . . On nearly the highest part, which is a rich shell soil, Dr. Phillippi fifty years ago planted seed which came from Cuba. After the war [1861 to 1864] the place was neglected to a considerable extent, and the orange trees are now dead or dying, while the grapefruit trees are in a thrifty condition, bearing annually large crops of very excellent fruit. It would therefore appear that the grapefruit can safely be planted in shell lands where the sweet orange, under certain conditions, is comparatively short lived."

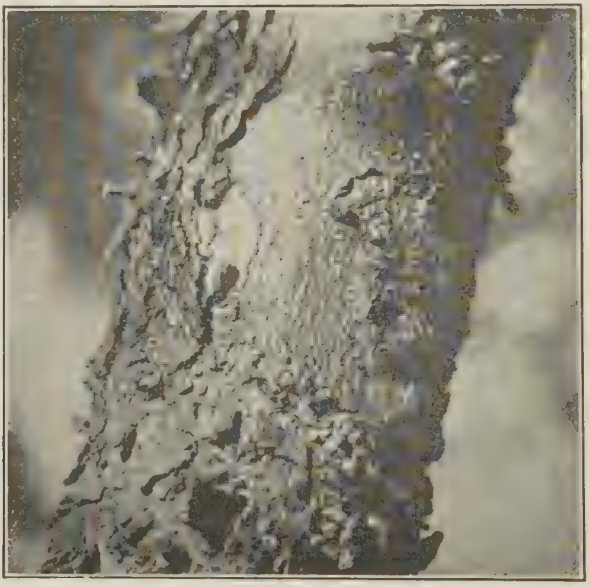

FIG. 68.—Later stage of leprosis in Florida not easily distinguished from psorosis.

These poor conditions of the orange trees spoken of by Duncan appear to have been due to this disease rather than to the land being filled with shell, because orange trees in this same region on other kinds of soil are also injured by leprosis, while grapefruit is nearly immune.

Symptoms.—In order to identify leprosis in the orchard and distinguish it from other diseases, it is necessary to look for the following characteristic symptoms:

1. On the smooth bark of branches, six to nine months old and older, will be found more or less round or oval spots 1/6 to 1/2 inch (4 to 12 millimeters) broad, raised above the surface, mahogany red, chestnut or auburn in color, with well-marked edges (Fig. 38 and 67). As the spots grow older, the bark becomes glazed and then brittle, develops cracks running lengthways and at last breaks into small flakes and scales. Older spots may be mikado brown to sayal brown in color. In severe cases of

leprosis, these spots increase in number till they join together, forming large patches of scaly and scabby bark (Fig. 68).

2. On the larger limbs and sometimes on the trunk as well will be seen patches of rough bark, the small pieces of which shell off as the hand is passed over them. In some cases, this roughness of the old bark may be absent. In this later form, it is not easy to distinguish the effect from that of older stages of psorosis.

3. On the fruit will usually be found brown sunken spots, some of which are apt to be in the form of sunken rings (Fig. 182). These spots at first may have a chestnut-brown center with a lemon-yellow halo which fades imperceptibly into the normal green of the immature fruit; finally the center becomes dark and sunken. In ringed spots, the rings first become sunken, with a higher part inside. This central part afterwards sinks in, and the whole area inside the ring becomes dark. The spots vary in breadth from 1/5 to 1/2 inch. The spots are quite superficial and shallow at first, but later the discoloration may extend inward a very short distance (p. 483).

Leprosis differs from psorosis in the following points: Leprosis affects all portions of the tree aboveground from the trunk to the smallest twigs, and the fruit and sometimes, but rarely, the leaves. Leprosis is almost entirely confined to the sweet orange, while psorosis severely affects the grapefruit and some other varieties as well.

Leprosis differs from canker in the following points: The spots on the twigs are more glazed and hard, not spongy nor so prominently raised from the surface. The spots on the fruit are not raised above the surface nor are they spongy. Leprosis seriously affects sweet-orange trees but rarely grapefruit, while canker affects both grapefruit and oranges, the former more seriously than the latter.

Development of Diseased Spots.—The diameter of the spots on branches, when first noticeable to the unaided eye, is about 1/25 to 1/6 inch (1 to 4 millimeters). They are circular or oval to irregularly angled, and first became evident in the following forms: (1) faint lemon-colored spots; (2) raised or ruptured chestnut or auburn-colored portions of bark; (3) circular yellowish bands with a raised portion in the middle.

In most cases, the beginning of the spot is marked only by a lemon-colored area, which at its first appearance is nearly the size of the fully matured spot. The bark on the affected area gradually becomes hard and brittle, and in the course of eight to ten months the spots develop well-defined margins. At this stage, they may be 2/5 to 4/5 inch (10 to 20 millimeters) in diameter. The bark is raised, becomes brittle and begins to crack and form small flakes or scales. These spots are at first scattered but may increase in number to such an extent as to become joined together. The branch is rarely killed the first year. During the second year, additional spots form between the old ones, and this may go on for several years until the branch is finally girdled at some point and killed. On new spots, only the epidermis and a few layers of cells below appear to be affected. As the spots develop, there is an increase of the parenchymal cells, and sometimes a new bark is formed under the old as the latter cracks and flakes off. Larger branches, when not too badly diseased, will live on for years with the old marks of leprosis upon them.

When branches that have been diseased for some time are cut transversely, tracts containing loose tissue filled with a gummy substance may often be found between the different rings of growth in the wood. In many instances, these tracts seem to be entirely enclosed by a layer of healthy wood cells, while the branch keeps on growing and forming new layers of wood and new cortical cells at the cambium zone. In badly diseased stems, a false cambium appears to be formed within the bark, and some of the inner cortical cells are cut off from the rest, leaving diseased patches inside or between the rings of wood. In some cases, darkened patches of wood are found opposite the diseased areas, extending for a number of layers inward, indicating perhaps that the live tissue had succeeded in cutting off the infected patches for a number of years in succession. The course of development on the fruit is described on page 483.

Causal Agent or Agents.—Investigations as to the cause of leprosis in Florida have indicated that a fungus similar to *Cladosporium herbarum* Lk., which has been known as *C. herbarum* var. *citricolum*, may be responsible for the initial spots and that *Colletotrichum glœsporioides* and other fungi may be important secondary agents in the apparent destruction wrought by the disease in later stages (Fawcett and Burger 1911*b*) (Fawcett 1911*b*). *Phomopsis citri* and *Diplodia natalensis* are also frequently found in the dead twigs and branches that accompany this disease under Florida conditions. Although the investigations appear to show that this strain of Cladosporium is a factor in starting the initial spots, the investigator wishes to express reluctance at this time to accept without some reservations these earlier findings until they are confirmed.

The Fungus in Diseased Tissue.—An examination of the diseased areas at different seasons of the year showed that the fungus occurred most often in its one-celled Hormodendron-like form during warm weather, while during cooler weather spores of the two-celled Cladosporium form increased.

During the fall and winter, which is a dry season in Florida, spores of a Coniothecium form were seen, and also microsclerotia. These three forms of spores and the microsclerotia were also seen in cultures of the fungus of different ages and on different media in the laboratory, as well as at different seasons on diseased trees. The two first mentioned forms of spore, together with the formation of microsclerotia, have been observed by Bancroft (1910) in forms of *Cladosporium herbarum* on various plants in England. On the youngest spots, the spores and hyphæ are usually hyaline to only slightly colored, but, as the spots become older, the hyphæ and spores became more straw colored or smoky.

The spores from the spots, by numerous measurements, were found to vary much in size. The one-celled spherical Hormodendron-like spores measured from 3 to 6μ in diameter. The Cladosporium-like spores measured, when one celled, 6 to 9 by 3 to 6μ, and the two-celled spores measured 8 to 12 by 4 to 6μ. The small hyaline hyphæ measured 1 to 3μ and the older colored hyphæ were 2 to 6μ in width, with segments 6 to 9μ long (Fawcett 1911*b*).

The Fungus in Cultures.—In general, on various media, the diameters of the spores and hyphæ of *C. herbarum* var. *citricolum* were slightly smaller than those of *C. herbarum* Lk. obtained from Dr. Westerdiyk, Amsterdam. The spores of the former were usually strictly Homodendron-like and, under favorable conditions, many times more abundant.

Comparison of the two varieties of Cladosporium on standard beef-peptone agar showed that, in general, with the leprosis fungus, the mycelium grew slower, the hyphæ branched more quickly, the colonies became denser and lighter in color and the range of resistance to either high acidity or high alkalinity was much more limited than the *C. herbarum* Lk. from Westerdiyk. The oval spores of the former were 5 to 8 by 4μ in size, while those of the latter were 6 to 12 by 5 to 6μ (Fawcett and Burger 1911*b*).

Contributing Conditions.—Some of the contributing factors in the occurrence of leprosis or nailhead rust are age of tissue, susceptibility of varieties, and possibly climatic conditions and injuries.

Age of Tissue.—Leprosis makes its first appearance on twig tissue at least six months old and on fruit about four to five months after the bloom has been shed. The tissue, whether it be a twig, leaf or fruit, is usually near to the end of its maturation period before the spots become visible. Under Florida conditions, it was found that new spots made their appearance on the twigs at any time of the year, but the greater number of them first appeared between about June 1 and Dec. 1. During the other months of the year, some new areas appeared, but not in such great numbers, nor did they develop so rapidly. The diseased areas on the fruit first appeared about the first of July, and spots made their appearance from that time until the fruit had ripened. They became most apparent when the fruit began to color. Inoculation experiments showed that the fungus spores failed in the greenhouse to infect growth that was less than four months old, and produced most infections on stems five to eight months old at the time of inoculation. If forty to sixty days are allowed for the first appearance of the spot after infection, as shown by inoculation tests, the observed age of the earliest spotted stems in the grove agrees almost exactly with that shown by the trees inoculated in the greenhouse.

Susceptibility of Species and Varieties.—The sweet orange, *Citrus sinensis*, appears to be the only commercial variety that is badly affected. The disease has been reported in one case as occurring in fairly severe form on rough-lemon seedlings (a horticultural variety of *C. limonia*).

It has also been seen in a mild form on grapefruit (*C. maxima*) and sour-orange (*C. aurantium*) twigs, but, as a rule, these varieties are very resistant, even when surrounded by badly diseased sweet-orange trees. The mandarin-orange varieties (*C. nobilis* var. *deliciosa*) appears to be immune to the disease.

Climatic Conditions.—While little is known definitely regarding the relation of this disease to climatic conditions, it is suspected that its severity is influenced by moisture conditions. F. M. O'Byrne of the Florida Plant Board has drawn our attention to the fact that all known cases of this disease are in fairly damp localities near bays, lakes, rivers or swampy "hammocks." It is quite likely that moisture at the right season for infection is an important factor in its severity.

Control.—The experiments conducted in Florida by Fawcett (1911*b*) showed that the injury from leprosis on the branches and fruit could be greatly lessened and almost completely eliminated by either spraying or pruning.

We are indebted to F. M. O'Byrne and O. F. Burger for observations since these experiments were made in which they confirm the value of spraying with Bordeaux mixture. They would recommend Bordeaux-oil emulsion (3-3-50 Bordeaux with the addition of 1 per cent of oil) in order to lessen the danger of increase in scale insects. Pruning out thoroughly as many of the diseased branches as possible also proved highly beneficial. Observations since this time show that in many groves the disease is well controlled by pruning alone. A combination of pruning and spraying would presumably lead to the most effective control.

Based on the experimental data and subsequent observations, we would recommend one of the five following lines of procedure·

Spraying.—Spray with Bordeaux-oil emulsion (3-3-50 with addition of 1 per cent of oil) about February before the blossoms open. As the diseased spots and scabs are located almost entirely on the branches, large limbs and trunk, and not on the leaves, care should be taken to spray the interior of the tree thoroughly. Spraying should be done so as to cover the trunk and larger limbs, and also the entire surface of the wood out to the smallest twigs and fruit. If the spray is thrown on from the outside, most of it will be caught by the leaves, and but little benefit will result.

Spray the second time with the same mixture soon after the fruit is set, at least before two months have elapsed from the time of shedding of the blossoms. The first infection of the fruit by the organism, considering forty to sixty days for the incubation period, is two to four months after blossoming time.

Spray the third time about two months after the second. This third spraying is for protection against later infections on the fruit and twigs.

During the second year, probably only two sprayings will be necessary, since there appears to be a considerable hold-over effect from the spraying and pruning of the previous year. Omit the first spraying and spray only at the times indicated for the second and third applications of the first year. For the third and subsequent years, it will probably be sufficient to spray once only when the fruit is well set at least within two months after the blossoms fall.

This is perhaps a maximum schedule and is applicable to very badly diseased trees. If trees are only slightly or moderately affected, one spraying per year will probably be sufficient from the first year on.

Pruning and Spraying.—A more effective procedure on severely affected trees is to follow the first spraying mentioned in the foregoing with a thorough pruning, taking out all dead wood and, as far as possible, badly diseased suckers and weakened branches. The effect of such treatment alone is beneficial in lessening the sources of infection. All prunings should be burned and tools used in diseased trees disinfected before they are used in trees free from the disease. Where thorough pruning is done, the first two sprayings mentioned under spraying will probably be sufficient for effective control. In certain cases that are not severe and where the fruit is not spotted, a thorough pruning followed by one thorough clean-up spray with the Bordeaux oil may be sufficient.

Heading Back.—For very bad cases, during the dormant period, December or January under Florida conditions, cut out the top, leaving only the trunk and the stubs of the larger branches. Then paint the entire bark with Bordeaux wash, or spray the bark surface with a 3-3-50 Bordeaux emulsion. This should be followed by three additional sprayings, about eight weeks apart, as the new growth comes on.

Heading Back and Carbolineum (Avenarius or Arrow Brand).—Another method which has been quite successful in the experiments carried out in Florida is heading back of the tree, as described above, accompanied by the painting of the entire bark and cut surfaces with an emulsion of 1 gallon of carbolineum to 1 gallon of water to which 1 pound of whale-oil soap had been added. In the treatment of the disease in this way, which began in February, the bark assumed a dark-red color. In a few weeks, as the growing season came on, the trees put out new shoots and by the end of summer had grown a vigorous, healthy top. By that time, the disease had disappeared, and the bark had become smooth and free from flakes. The carbolineum appeared to have stimulated increased vigor. Unless the entire grove is treated in this way, the young growth should be protected by spraying with a good fungicide in May or June when the new wood will have hardened.

Top Working to Resistant Varieties.—Grapefruit and mandarin oranges appear to be nearly immune to leprosis, even when surrounded by badly affected sweet orange trees. Diseased trees may, therefore, be top worked to one of these varieties. At first thought, this would seem to be too severe a remedy; but it can be carried out without serious loss at any one time. This can be done by treating only alternate trees in a row, or by treating alternate rows. In this way the untreated trees will be found to produce a much larger crop, and this will in a measure compensate for the loss of crop on the top-worked trees.

During December or January, before any spring growth has started, cut off all the large limbs as for ordinary top working. Then top graft the trees. If the grafts fail to take, the sprouts that start from the large limbs and body of the tree may be budded at the proper time. As a further precaution, the trunks and branches may be treated as suggested under Pruning and Spraying. When these top-worked trees begin to produce a fair crop, the untouched trees may be treated in the same way.

LEPRA EXPLOSIVA

This disease described by Spegazzini (1920) is reported to be widely distributed and possibly endemic in Paraguay, where it is especially prevalent in the northern region. It has also been found in Argentina. Spots begin on the shoots of the current year and continue to develop and enlarge on shoots of the second year. Finally, it spreads down to the main branches and upper portion of the trunk. The disease resembles leprosis of Florida in some of its characteristics, but is thought to be distinct. It is described as having three distinct phases with a different form of a fungus associated with each phase. Reproduction of the lesions by means of inoculations with pure cultures of these organisms will be necessary before their causal relation to the disease is definitely established. The following description is based on an abstract (*Review of Applied Mycology*, vol. 1, p. 349, 1922.) of a publication by Spegazzini (1920).

Symptoms. *First Phase.*—It first appears on the vigorous succulent shoots of the current year as elliptical spots $\frac{1}{5}$ to $\frac{2}{5}$ inch (5 to 10 millimeters) in diameter. These spots are surrounded by a sharply defined furrow about 0.5 millimeter wide and are cinnamon to fawn colored and smooth except in the center, where a small, round, grayish sunken pit occurs.

> A little later, black granules appear in the encircling furrow and these rapidly become hemispherical about $\frac{1}{25}$ inch (1 millimeter) in diameter and flattened on top. They are corky-carbonaceous, hard, smooth, not shiny, and of the same color throughout." Without coalescing, these form a belt around the spot and develop into the spore stage of a fungus, *Pseudhaplosporella aurantiorium.*
>
> With the exception of this carbonaceous belt of pustules, the description of external symptoms up to this point indicates similarity to some of the spots of leprosis or nailhead rust of Florida as they develop on shoots, but later the similarity begins to disappear. The vascular bundles are blackened, and the cortex is changed to a reddish somewhat powdery mass. At this stage, colorless or grayish hyphæ are found in the affected tissues below the center and in union with the fungus fructifications.

Second Phase.—The spots increase in number, begin to coalesce and lose their typical form on twigs of the second year. Later the affected surface is covered with a tan-colored substance, wrinkled and furrowed, and with numerous regular or irregular fungus pustules. The leaves on affected twigs turn yellowish and roll up at the margins and fall off. Internally, the woody tissues are normal except for a gray tint, but the inner bark (phloem) is profoundly altered, being swollen and friable, and containing thin bundles of dark mycelium.

Pustules 0.5 to 2 millimeters in breadth and 0.25 to 0.5 millimeter in height constitute the spore stage of *Paradiplodia aurantiorium.* Associated with this second phase, there are found sometimes spore-bearing fungus stroma with depressions lined with spore-bearing hyphæ and fringed with a circle of stout hair-like bodies (setæ) with blunt, obtusely bifurcate branches near the tip. The spores are straight or curved, hyaline, three to five septate and 40 to 50 by 4 to 5μ.

Third Phase.—In this third phase there is a further extension of the spots downward to some of the main branches or even to the upper portion of the trunk from which it may ascend other main branches. Sometimes a restricted number of isolated eruptive lesions of fairly large size are on the principal branches and trunk. In this last form nodules are formed from within (endogenously)

> . . . producing first a swelling of the cortex and later with pressure from within rupturing the bark and causing three or four radial rents which may be up to 2 inches (5 centimeters) in length. Lesions may reach a length of 8 inches (20 centimeters) and a width of 2 inches (5 centimeters) and are whitish without exudation or secretion.

The final effect on the tree is defoliation and the appearance of suckers from the base, which often dry up suddenly without apparent cause. The fungus pustules continue to increase on the branches and twigs.

At this phase some of the fungus stroma develop a perfect stage of a fungus, *Amylirosa aurantiorum,* which have perithecial cavities in single or double rows without openings (ostioles). The spore sacks (asci) are cylindrical, 80 to 100 by 10 to 14μ in size, obtusely rounded at the apex and contain eight elliptical, fuliginous spores with one to five septa and often a vertical septum in one of the central cells. These spores are 15 to 20 by 6 to 8μ and are slightly constricted at the septa. Paraphyses are also present.

Control.—It is recommended by Spegazzini (1920) that trees affected by lepra explosiva be removed and burned and that the plantations should be cleaned up by gathering up fallen twigs that may bear the fungus. Spraying with Bordeaux mixture is also recommended. No experiments in control are reported.

RING BLOTCH

Ring blotch is a spotting of the leaves of unknown cause said to be very widespread in South Africa and especially troublesome in the Transvaal and Rhodesia. It has not been reported in any other country.

Most varieties of Citrus are affected in South Africa, but the disease is especially conspicuous on the navel orange. It has been known for many years in South Africa.

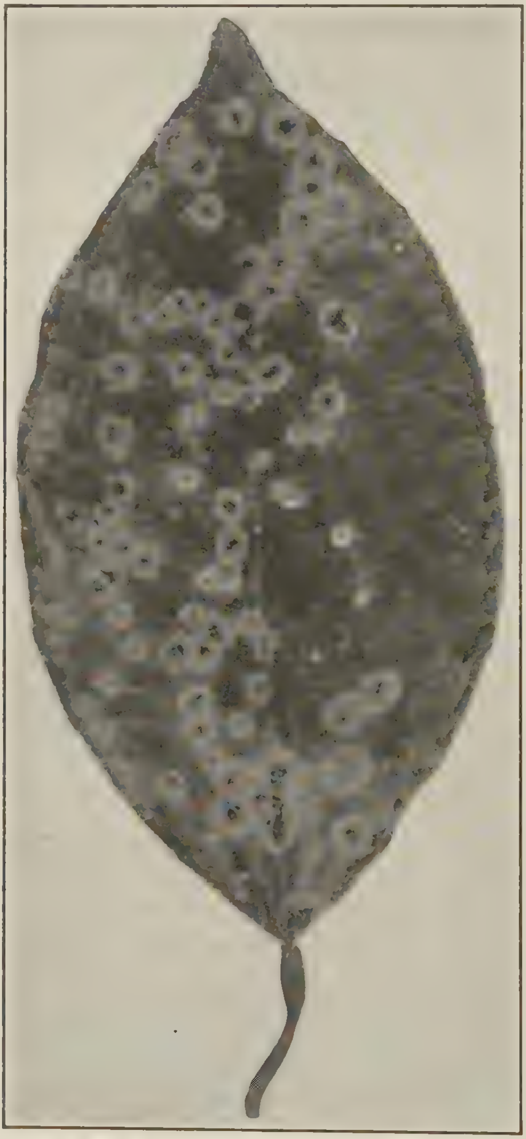

Fig. 69.—Ring blotch of South Africa, cause unknown. From herbarium specimen sent from Rhodesia.

Symptoms.—Ring blotch is usually seen on the leaves, but in severe cases may occur on twigs and occasionally on fruit. It is clearly described by Doidge in "Citrus Growing in South Africa" (Davis 1924), from which the following is extracted:

> Minute yellowing rings surrounding a dull-green center first appear on the upper surface. These increase in size, and not infrequently two or three concentric rings are formed. The upper surface of the leaf thus becomes thickly covered with ring blotch, one leaf frequently showing several hundred irregularly circular, yellow spots, 3 to 5 millimeters in diameter, with concentric zoning. These show on the under surface as indistinct yellow spots. Frequently, the circles are less clearly marked, or they may be replaced by large blotches, irregular in shape, which have a distinct yellow margin and often show concentric zoning (Fig 69).

Gum formation commonly accompanies ring blotch. The upper layers containing the epidermis and palisade cells are filled with a brown gummy substance which raises the cuticle and forms a brown blister on the leaf surface. This part of the disease is not unlike the gum spot of the leaf. Gum may be produced not only at the center but at the yellow margin of the blotches. Old leaves sometimes lose all their green coloring matter. When severe, the disease has a tendency to cause partial or almost complete defoliation.

Theories as to Cause.—The cause of the disease is not known. Doidge suggests three possibilities: a parasitic organism, unsuitable soil condition or an infectious mosaic disease. Since many hundreds of specimens have been examined without finding any organism, Doidge concludes that

> The disease is probably due either to some unknown factor in the soil condition or to a filterable virus similar to that which has been found to be the cause of tobacco mosaic. The fact that the disease is not severe on soils with plenty of humus and that it is largely controlled by the use of manure and cover crops suggests some lack in the soil.

Contributing Conditions and Control.—As pointed out by Doidge, the cause is not known, and only a few points have been ascertained as to the contributing conditions. It is said to be absent on "humus" soils in South Africa and to have been reduced to a minimum at the Experimental Orchard at Warmbaths by the use of systematic green manuring, velvet beans and cowpeas being the best cover crops for the purpose. Doidge suggests great care in selection of seeds for nursery beds and in selection of bud wood in propagation.

EXANTHEMA

Exanthema, also known in Florida as "dieback," appears to be a malnutrition disease, the various symptoms of which are seen most conspicuously in the newer branches and fruit. When severe, it seriously affects the tree as a whole, dwarfing and stunting it.

History and Distribution.—Exanthema has been reported in nearly every country where Citrus is extensively grown. The disease was mentioned in Florida as early as 1875, but has probably been present ever since Citrus trees have been grown commercially (Swingle and Webber 1896). It was found in California in 1896. It has also been found in Cuba, Porto Rico, Yucatan, Dutch Guinea, Brazil, Philippines, Hawaii, Italy and Australia. Exanthema was carefully described and illustrated by Swingle and Webber (1896), who concluded that it was a malnutrition disease. An investigation was conducted by Floyd (1913, 1917) who worked out the histology of the developing gum pockets and showed its relation under Florida conditions to certain forms of organic matter in the soil.

Symptoms.—Exanthema affects the branches, principally the terminal ones, the leaves and fruit. Except on very young trees, it seldom affects directly the main branches or trunk. According to Floyd (1917), the roots of severely affected trees are often lacking in fibrous roots and consequently in feeding tips. Root systems of trees less severely affected may show no apparent injury.

The five most common and conspicuous effects of exanthema are stained terminal branches, stained fruit, small gum pockets in the twigs, bark excrescences and multiple buds. In addition to these, there may be distorted or S-shaped branches, dying back of terminal branches, coarse, large, dark-green leaves in the first stages, changing to small mottled leaves in later stages, and gum at the center of the fruit at the angles of the radiating divisions or carpellary walls.

The more minute symptoms of the disease have been well described by Floyd (1917), whose general outline will be followed here.

Primary Symptoms.—Of the following primary symptoms, the bark excrescences, the stained terminal branches and the marked or stained fruit are the real distinguishing characteristics of the disease.

Gum Pockets.—The gum pockets develop at or near the leaf nodes in succulent branches before they have maintained full length. The bark is raised, giving the appearance of a large blister (Figs. 70 and 72) Between the wood and bark is a clear or amber-colored gum. As the stem grows older, new wood forms over the pocket and it finally disappears.

Bark Excrescences.—The bark excrescences are formed by longitudinal or rounded breaks through which gummous tissue is forced, resulting in a "double convex to rounded pad of crystal-like gum on the stem." These may form along the terminal stems, mostly near the base, in the bark of the fruit spurs, or in the leaf axil among the buds. In a year or more, new bark is formed below and the diseased excrescences slough off (Figs. 71 and 91).

Stained Terminal Branches.—A stain occurs on young, somewhat succulent growth as a "brownish, glossy, gum-soaked condition in only slightly raised spots and irregular areas." It is caused by the "closing of the epidermal and subepidermal cells with a gum-like substance." is

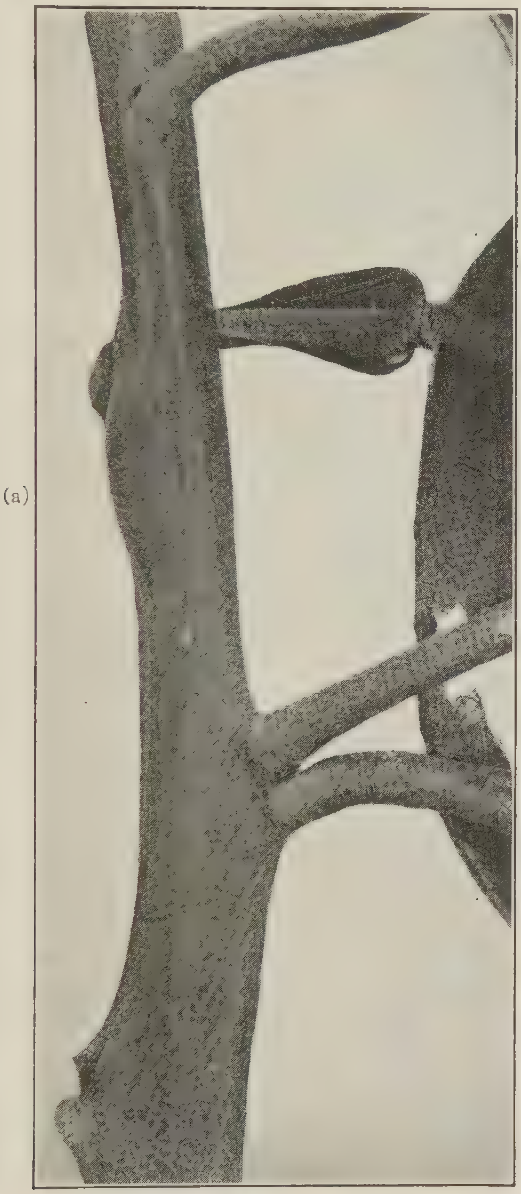

Fig. 70.—Surface tissue pushed up in form of blister by pressure of gum within at (a). Magnified about 2 diameters. (*After Floyd* (1917).)

usually confined to the terminal stems and may extend out also on the petioles and bases of the leaf blades. In severe cases, these stained

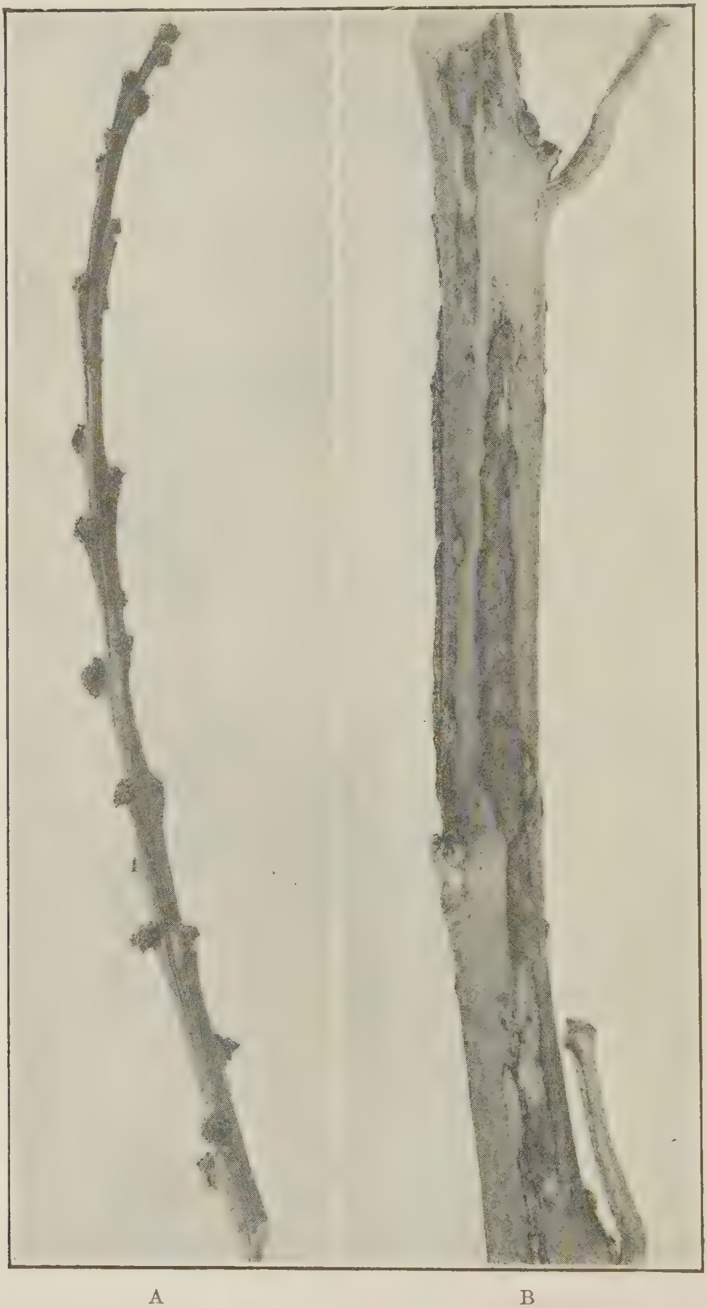

FIG. 71.—Symptoms of exanthema on twigs; A, multiple buds; B, excrescences on bark. (*After Floyd* (1917).)

terminal twigs die back partly from invasion of secondary organisms, giving the common but inappropriate name, dieback, to the disease.

Marked or Stained Fruit.—The same "brownish, glossy, gum-soaked areas" that occur on twigs may also occur on the rind of the fruit. (Figs. 71 and 188). The markings occur most commonly on the side or lowe. half of fruit. Such fruit frequently splits and drops. The splitting varies with conditions. Gum may also occur in the angles of the segments surrounding the seeds (p. 501).

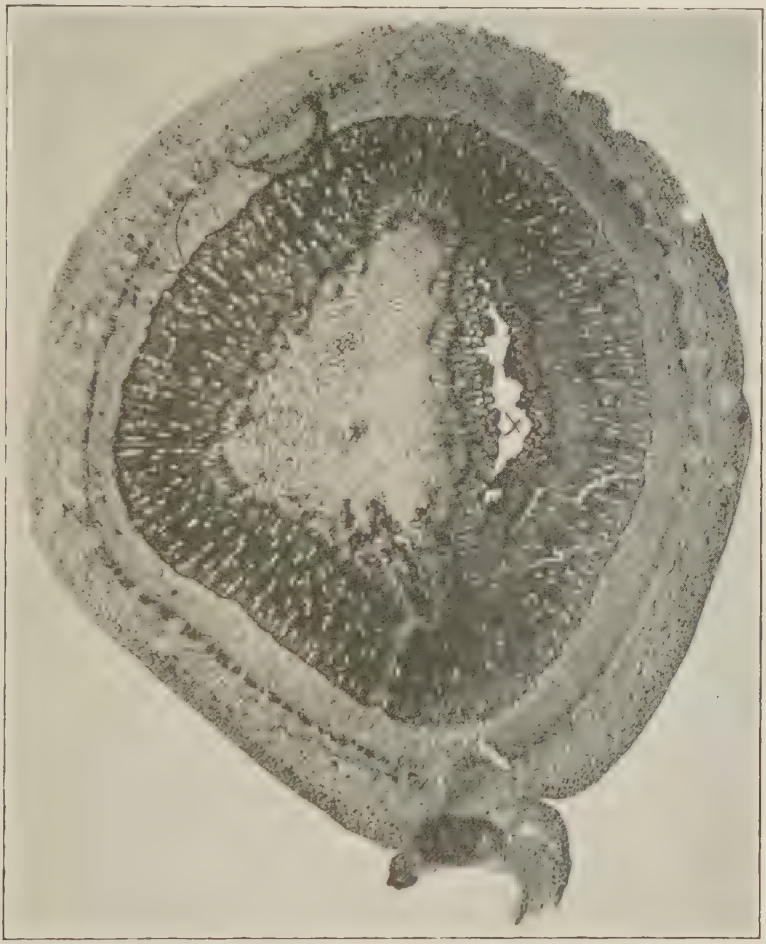

Fig. 72.—Stained cross section of a Citrus twig affected with exanthema, showing gum pocket at x in the inner woody cylinder. Beginning at the outside one sees in order of occurrence (1) the epidermis, (2) cortical layers and sieve tube region of the bark; inside this (4) the wood and finally (5) the pith cells in the center. Rows of oil glands and bast fibers are seen in the bark area. The gum pockets result from hydrolysis of the cellulose walls. Magnified 10 to 15 times. (*Photo from section contributed by J. T. Barrett.*)

Multiple Buds.—Clusters of several to thirty or more buds in a leaf axil where normally only two would occur is also a frequent accompaniment of the other exanthema symptoms. There is usually gum formation in the cambium region among the buds (Fig. 71*a*).

Secondary Symptoms.—Certain disturbances may arise which are incidental to the development of the disease but which are not necessarily diagnostic characteristics and may be found in trees not affected by exanthema. Floyd has enumerated these as follows:

Deep-green Color of Foliage.—Trees on the verge of exanthema and growing under favorable food and moisture conditions may show unusually large deep-green foliage, giving to the unpracticed eye a very promising appearance. Experienced Florida growers have learned to anticipate the outbreak of exanthema by this condition.

Frenching or Mottle Leaf.—This condition frequently accompanies exanthema, but is not a diagnostic symptom in itself, since such a condition often occurs independently of exanthema (see Mottle Leaf, p. 336).

Abnormal Leaves.—Leaves may be thick and coarse and of a different shape from those of a healthy tree.

S-shaped Branches.—Branches which appear to be bent over by their own weight and start to grow upward again, giving an S-shaped appearance, are frequently found in trees affected with exanthema. This condition sometimes precedes the development of the disease.

Rosette or "Stag-horn" Growth.—The development of branches from the multiple buds frequently results in a bushy rosette-like growth. The internodes may also be shortened and with unusual branching cause a thick bushy head, which in lemon trees in California is often referred to as a "stag-horn" appearance.

Theories as to Causes of Exanthema.—The cause or causes directly responsible for the effects known as exanthema are not known. No organism has thus far been found that could be considered as a factor in producing the lesions, and experiments and observations indicate that it is not an infectious or contagious disease. All attempts to transmit the disease from diseased to healthy trees have so far failed, and trees readily recover when moved to soils or situations unfavorable to its development. The possibility that some obscure organism is a factor either directly or indirectly cannot, however, be definitely denied at this time according to Floyd (1917). Floyd (1917) suggests as a working hypothesis:

> . . . that the disease is due to the injurious action of some organic chemical compound or compounds obtained from the soil upon the growing cells in certain of the plant parts; that these chemicals do not kill the cell but induce abnormal processes in the living matter whereby a particular type of gum formation results; that the organic chemicals are formed by the decomposition of organic matter and that they are formed under certain limited conditions.

Contributing Conditions Favoring Exanthema.—In Florida, where there is a preponderance of sandy soils and where exanthema is common, the following conditions have been observed as favoring its occurrence: (1) stables, outhouses, cesspools and poultry yards, where the roots feed in manures, garbage and other organic matter; (2) dead animals or other offal buried near the trees; (3) large quantities of rank cover crops or organic nitrogenous fertilizers turned under; (4) excessive cultivation; (5) hardpan too near the surface; (6) lack of drainage so that the roots are water logged, etc.

In California or other sections, on heavier types of soil the first four factors do not so commonly contribute to the occurrence of exanthema, but hardpan and lack of drainage may bring it about under certain conditions. In California, the disease is sometimes found also in small local areas which correspond to locations of former sheep corrals or cattle barns. In some places, a light sandy soil underlaid with gravelly subsoil is also subject to the disease. It has also been observed in places where the soil has been graded in order to fill up inequalities.

In Victoria, Australia, according to Brittlebank (1912), the conditions favoring the disease are: (1) porous, light, deep, coarse or sandy soil; (2) continuous drought followed by heavy rains; (3) large amounts of organic nitrogenous manures.

Control.—Methods of prevention and treatment, based for the most part on experience and observation rather than on a definite knowledge of the cause of the disease, have been adopted in Florida where the disease is most common. These methods are probably not all applicable to conditions in other Citrus-growing countries, but will be described first and followed by certain comments as regards conditions for California and other countries. As pointed out by Floyd, it is necessary to exercise judgment and a knowledge of conditions under which affected trees are growing to prevent or treat exanthema successfully. This is because of the varying conditions that contribute to its occurrence. To determine the most probable contributing conditions and to remove these are the principles on which control should be based.

Prevention in Florida on Sandy Types of Soil.—Where it is clearly evident that exanthema has been induced by overfeeding with organic nitrogenous materials, a temporary nitrogen starvation may be helpful. If nitrogen is omitted, it should be from one application only, and the succeeding applications should contain low applications with successive increases of nitrogen (all from mineral sources) until the normal amount is again reached after two or three applications. This nitrogen starvation is not necessary in all cases of exanthema. On certain California soils, in cases not brought on by overfeeding, the proper use of organic nitrogenous fertilizers may even be beneficial in correcting exanthema. Even under Florida conditions in dry, sandy, high pine lands where the exanthema is not brought on by overfeeding, limited amounts of stable manure may be helpful in curing the disease (Floyd 1917).

Stopping cultivation during most of the year is also helpful in Florida under certain conditions. The common practice when exanthema is not present is to plow the grove either in the fall or early spring and harrow only during the spring months until the rainy season begins. The soil is then let alone for the summer to allow grass, weeds and cover crop to cover the ground. This growth is cut in the late summer, and either allowed to lay on the soil to rot or is removed for hay. Plowing does not usually exceed 6 inches in Florida bearing groves. In young groves, it may be shallow near trees and deeper in the middles. When exanthema is prevalent, this practice may be modified to avoid any plowing. The "disk" harrow rather than the plow is used when it becomes necessary to break up sod. Mulching trees with heavy covering of grass, weeds or legumes is, except for the danger of fire, a good substitute for plowing to hold moisture in a dry season.

When lack of drainage is the contributing cause for exanthema, the removal of the excess of water is, of course, the means of prevention. This excess may be due to high water table in low lands or to basins or pockets formed by hardpan in higher land. When drainage is not possible, exanthema has been corrected by actually raising the trees and throwing up soil under and around them to form mounds. In the Florida "hammocks" or semiswampy lands, large successful orchards on sour-orange roots are grown on such mounds from the time of setting out.

When hardpan is a contributing cause for exanthema in Florida, this may often be broken through when thin with hand tools or dynamite to allow movement of moisture between the upper and lower strata. If hardpan forms basins, as it often does even on sloping land, these should be broken through by means of ditches to establish drainage. Hardpan consisting of clay or marl may be broken by dynamite to allow the roots room to grow, but good drainage in such cases should not be lacking.

Under the usual California conditions, the above methods apply only in part. In certain cases brought on by lack of drainage or hardpan, the same methods of removing excess of water and breaking up of hardpan are, of course, to be resorted to. Under other conditions, such as exanthema on spots where land has been graded, the disease appears to disappear gradually under good cultural and irrigation practice. The liberal application of stable manure or other nitrogenous fetilizers, rather than the lack of it, appears to be helpful in some cases.

Treatment.—Certain methods of directly treating badly diseased trees have also been employed in Florida, but not so far as known elsewhere. These consist of the use of copper sulfate in three different ways: (1) spread on the soil, (2) placed under the bark and (3) sprayed on tree in form of Bordeaux mixture. Floyd (1917) reports all these methods as curative but not under all conditions.

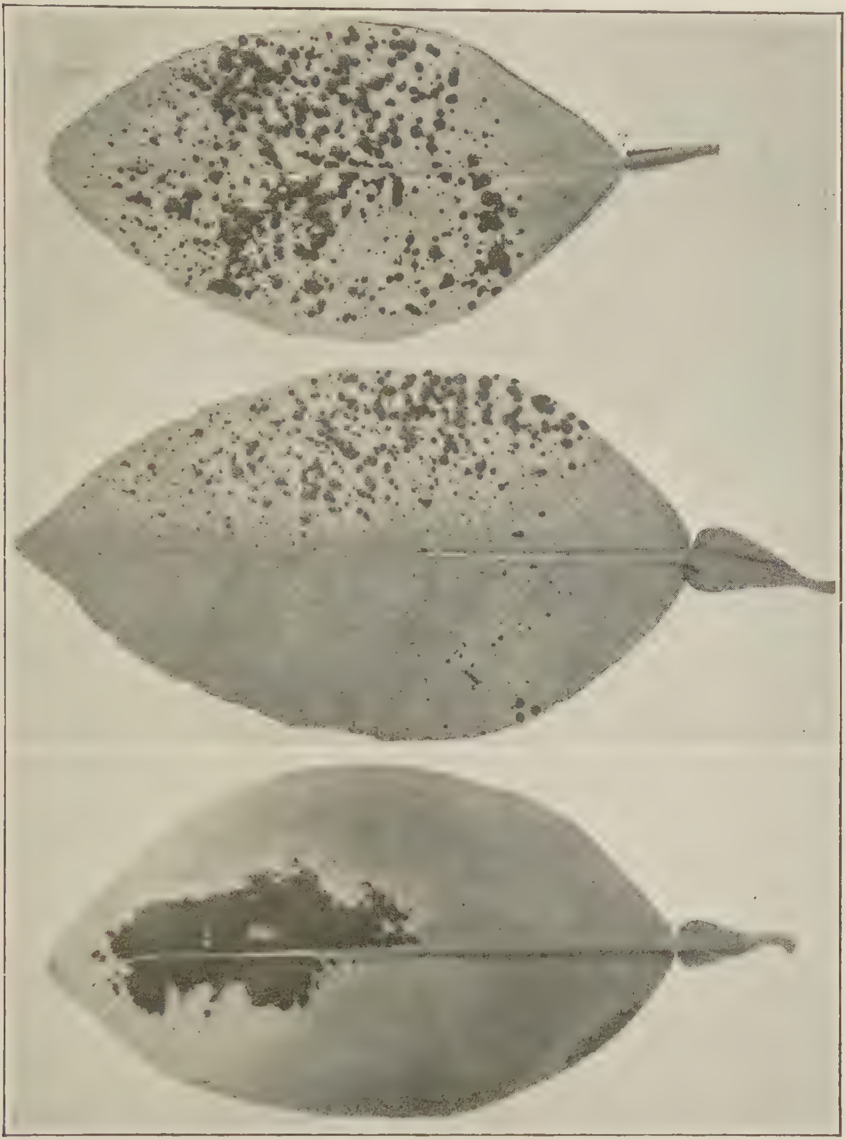

Fig. 73.—Two types of gum spots on Citrus leaves in California thought to be caused by slight frost followed by effects of bright sunshine. The tissue is raised and impregnated by a dark, vitreous-like gum.

When spread on the soil, from $\frac{1}{4}$ to 1 pound is usually employed for each tree, depending on size. When more is used, care must be exercised to prevent root injury.

When placed under the bark, a crystal from the size of a wheat grain to that of a pea (about 2 to 6 millimeters) in diameter is used, varying with size of the tree. This often splits the bark and is likely to cause harm. It is not generally recommended.

When used as Bordeaux mixture, a 3-3-50 Bordeaux-oil emulsion may be used just prior to the flush of growth in which exanthema is expected to develop. Experiments in Florida with Bordeaux applied in February and April were reported by Collison (1919) as distinctly beneficial in controlling the disease.

GUM SPOT OF LEAF

Small, raised pustules, usually of a brown or dark-brown color and varying in size, are very common on Citrus leaves. Some of these pustules when small are about the size of melanose, canker and other lesions, and thus might easily be mistaken for definite infectious diseases by one not experienced in identifying them. They are usually smooth and hard on the surface, and when examined more carefully are seen to consist of a small area of surface cells impregnated by a hard gum-like material (Fig. 73). They are thought to be produced by various causes, especially by a slight frost followed by bright sunshine. They appear also to be induced by slight sunburning and possibly also by certain spray materials and by effects from fumigation with hydrocyanic acid gas. Development of these spots is a subject which needs further investigation. It is of interest to note that an illustration by Penzig (1887, Plate 2) represents a Citrus leaf with typical gum spots on it.

CHAPTER XII

SUPERFICIAL MARKINGS, PUSTULES OR COATINGS

SOOTY MOLD

Sooty mold is a black coating on the surface of the leaves or fruit composed of a weft of black mycelial threads of several different species of fungi, principally *Capnodium citri*. The sooty mold is abundant throughout the Citrus-growing sections of the world wherever honeydew-secreting insects are found on the trees.

Sooty mold is especially abundant following the presence of insects such as the white flies in Florida and the black scale in California. This fungus does not enter the tissue but lives entirely on the surface in the honeydew secreted by scale insects, aphids, larvæ of the white flies or any insect that secretes sugary substances of this nature. Even though the sooty mold does not attack the tissue in any way, it interferes with the normal functioning of the tree and is a sign of the presence of some insect pest which it accompanies. An excellent description of this fungus and the nature of the injury has been given by Webber (1897).

Appearance.—Sooty molds appear as black velvety membranous coatings over the leaves and fruit. If the insects are very few or the secretion of honeydew is slight in amount, this black mold may occur in limited spots, but when the honeydew is abundant the entire surface of the leaves, fruits and twigs may be covered by a dense continuous membrane resembling thin black tissue paper. This membrane is entirely superficial and may often be pulled loose from the leaf. With age, under very dry conditions, it may become detached and blown off in fragments by the wind.

Effect on the Tree.—When there is a very small amount of sooty mold, the effect on the tree may not be noticed, but when it occurs in abundance, it may seriously retard the growth, causing light blooming and flowering, and rendering the tree less resistant to drought. Leaves covered with sooty mold under dry conditions may curl and shrivel, while leaves not so affected nearby are free from this appearance. The black sooty covering interferes greatly with the photosynthesis and the formation of starches and sugars so necessary to the growth of the plant. The fruit is smaller in size and its rate of coloring is retarded. Fruit so affected is more likely to decay than normal fruit.

Characteristics of the Fungus.—The black thin membranes constituting the sooty mold are made up of densely interwoven branching threads (hyphæ). It is frequently a mixture of several different fungi, but principally a species known as *Capnodium citri.* The individual threads vary in color from olive green to deep brown, but when seen in mats on the surface of the leaf they are dark brown or black. The cells of the hyphæ are about 8 to 10μ in length and 6 to 10μ in width. The branches may anastomose, or adjacent hyphæ may become cemented together, thus forming a membrane that holds together like a film of paper. Disks composed of numbers of cells are also developed, probably as organs of attachment. The fungus has several forms of reproducing bodies: conidia, pycnidia, stylospores and perithecia (Fig. 74). The conidia are often simple cylindrical-shaped cells abscised from upright hyphæ but more complex in form. The stylospores are produced from small conidiophores developed within elongate flask-shaped structures 1 to 2 millimeters long which are rather distinctive and conspicuous. The pycnidia are relatively minute, black, about 40μ in diameter, containing quantities of small, one-celled hyaline spores. The stylospores are borne in flask-shaped conceptacles 1 to 2 millimeters long. The perithecia are black and spherical to elongate in form, sometimes bifurcate and are larger than the pycnidia, being about 80μ in diameter. They contain elongated asci, each ascus containing eight ascospores; the spores are brownish yellow, four or more celled, with both transverse and longitudinal septa (Webber 1897).

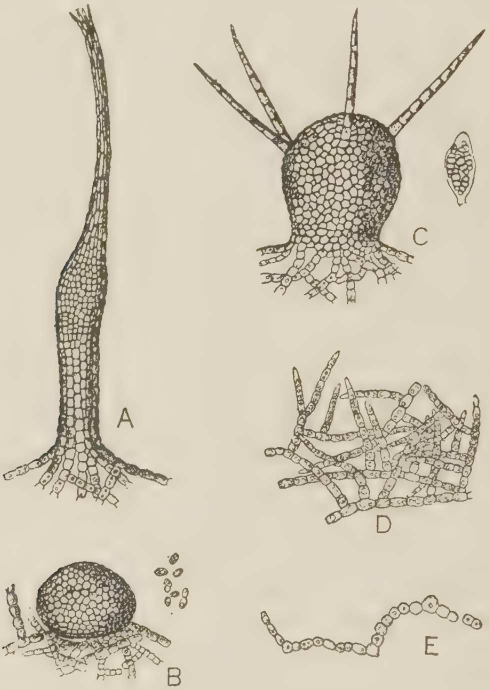

Fig. 74.—Sooty mold fungus: A, stylospore conceptacle ×80; B, pycnidium, ×90 with spores on the right ×125; C, perithecium and ascus on the right; D, mycelium ×90; E, conidia of the simplest form ×100. (*After Webber* (1897).)

Control.—Since sooty mold occurs merely as a saprophyte in the honeydew secreted by various insects, the prevention and treatment consist not in fighting the mold itself, but in carrying out methods for the prevention and control of the insects which bring it about. Soon after the insects are eliminated, the sooty mold also disappears for lack of suitable medium on which to propagate. The various methods employed for the control of the honeydew-secreting insects are: (1) use of natural enemies, such as entomogenous fungi and insect parasites; (2) spraying with insecticides; and (3) fumigation with hydrocyanic acid gas.

POWDERY MILDEW

A powdery mildew on Citrus leaves is very common in Java, Ceylon and India and has been reported from California. The mildew of California has been described as *Oidium tingitaninum* by Carter (1915), but there has been some question as to whether the Oidium on Citrus in the East Indies is identical. It is at least known that the diseases are similar and that in both cases the fungi are species of the genus Oidium.

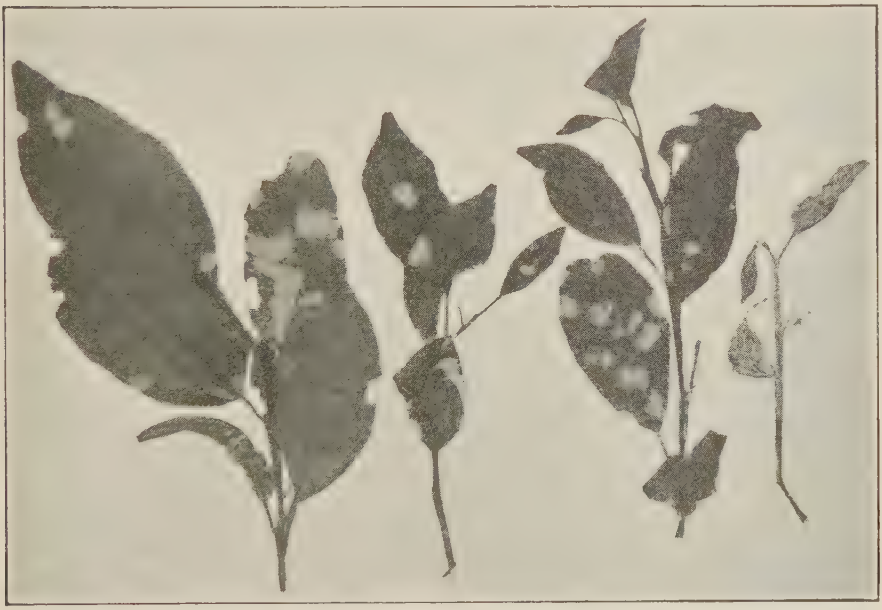

FIG. 75.—The mildew, *Oidium tingitaninum* on leaves and twigs of the mandarin orange, *Citrus nobilis* var. *deliciosa*.

The disease does not occur, or at least has not been reported as yet, from the Philippines, Japan, southern China, Australia, Florida, the West Indies, South Africa or the Mediterranean countries.

Symptoms and Hosts Affected.—Powdery mildew is readily noticeable and easily identified. Young, actively growing leaves and twigs are most commonly affected, and usually the young shoots near the center of the tree and nearest the ground show the disease. Suckers which are allowed to run from the base up into the center of the trees are very generally affected. White patches of mildew, most commonly on the upper surface of the leaves, are the most noticeable feature, usually starting at the edges or the midribs. This fungus does not spread in a perfectly circular manner, but the hyphæ may be seen to radiate from the original center of infection. The mycelium has a rather coarse appearance but is not dense. The leaf tissues beneath the fungus mycelium are at first a darker watery green than the normal leaf, and then as the disease progresses the tissues lose their color and become yellow. The infection on the very young leaves spreads rapidly and covers large portions on the leaf. Such young leaves shrivel, dry and adhere to the twig. Frequently, if the shoot is in a very succulent and actively growing condition, the hyphæ may spread from the leaves down onto the twig for several inches. On older leaves there is no shriveling, but a buckling of the tissues and a malformation. Shriveling of the young leaves, infection running down onto the twig, the radiating hyphæ and the malformation of the older leaves are all shown in Fig. 75.

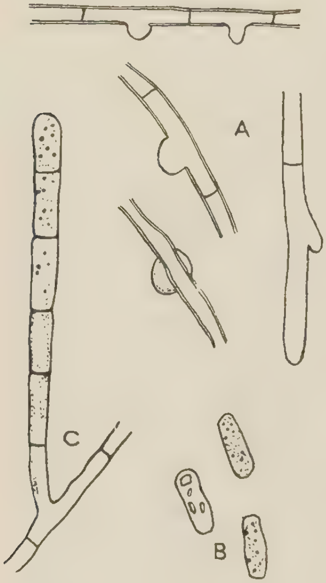

FIG. 76. A, appresoria on hyphae of the mycelium; B, a group of three conidia drawn from dried material; C, conidiophore with chain of conidia. All magnified 333.3 diameters. (*After Carter* (1915).)

In Java, mandarin oranges, *Citrus nobilis* var. *deliciosa*, are most commonly grown and are the hosts upon which this disease is most prevalent. In Ceylon, Petch (1914, 1915, 1919) reports the disease on mandarin oranges, lemon and sweet oranges. Petch also refers to the fact that an Oidium is found in Ceylon on *Aegle marmelos*, a native species of the family Rutaceæ to which Citrus belongs. The fungus in California was found only upon the Dancy-tangerine variety of mandarin oranges. Petch reports that in Ceylon the lime, *C. aurantifolia*, although commonly grown there, is not affected with mildew. Lemons, *C. limonia*, are not grown commonly in any of the East Indian countries, and although the disease has not been observed upon them, the negative evidence for that host does not mean that lemon varieties are entirely resistant.

The Causal Agent.—Many mildews have a perfect stage, but neither in California nor the East Indies has a perfect stage been found for the mildew on Citrus trees. Berkeley as early as 1874 noted the Oidium stage on Citrus, but in his specimens another fungus was also present which he misinterpreted as a perfect stage and so placed the fungus as *Erisyphe communis*. This has been shown by Petch to be incorrect, so that in the East Indies the fungus must be considered an Oidium species and probably the *Oidium tingitaninum* of California. The following is a summary of Carter's description of *O. tingitaninum:*

Mycelium not dense nor felty, mostly disappearing with age; hyphæ 4.5 to 6.7μ in diameter. Appresoria rounded; conidiophores 60 to 120 by 12μ; conidia in chains of four to eight, colorless, finely granular, barrel shaped with slightly rounded ends, variable in size 20 to 28 by 10 to 15μ. Carter's drawing of the fungus is shown in Fig. 76.

The spores of the Ceylon species are given as 36 to 42 by 15 to 18μ. The spores from the Oidium on Citrus in Java were intermediate in size 35 to 38 by 11 to 13μ. It seems probable that the spore size is variable, depending upon hosts and environment and that the East Indian and California species should be considered identical.

Contributing Conditions and Prevention.—The disease is apparently favored by warm summer temperatures and humid atmospheric conditions. Carter states that the most favorable conditions are apparently furnished by decidedly damp mornings when the sun does not come out until midday. In California, the inside leaves on the north and west sides near the ground were the most commonly attacked. This would apparently coincide with the location that would be the last to dry out after a heavy dew or fog. In Ceylon, the disease is reported as occurring near the close of each monsoon, about every six months. Although it occurs in California, it is not serious there and it would not be expected to be serious in such countries of the temperate zone, as Japan, Australia or the Union of South Africa. It would be expected to be more serious in Florida, the West Indies or the Philippines than in California. Even in Java, where tropical conditions favor the disease, it is not a major disease, but one which lessens the productivity of the trees by lessening the young foliage and the twigs which bear the flowers.

In considering preventive measures, efforts to exclude the disease entirely from such countries as Florida, the Gulf states and the Philippines where the disease does not yet occur would be most important. No experiments are on record for the control of mildew on Citrus. The mildews as a group are usually readily controlled by fungicidal sprays or dusts. Sulfur preparations are frequently employed. In tropical countries where the disease is of considerable importance, investigations along these lines would be most advantageous.

SEPTOBASIDIUM ON TWIGS

In Florida, Cuba, Brazil, Formosa and probably in a number of other moist climates, several fungus species of the genus Septobasidium are occasionally found encircling the twigs or small branches. Development may also extend to the petioles of the leaves. One of these fungi is *Septobasidium pseudopedicellatum* or *Thelephora pedicellata* of most American authors (Burt 1916).

Appearance.—This fungus forms a soft, felt-like, almost leathery covering completely surrounding the twig for 1 or more inches (Fig.

77). The surface is smooth and compact, while beneath it is soft and spongy. The entire enveloping cylinder is made up of minute mycelial threads closely woven or packed together. It is entirely on the surface and does not appear to penetrate the bark. It appears to harm the twig only indirectly. Twigs with this enveloping band often appear

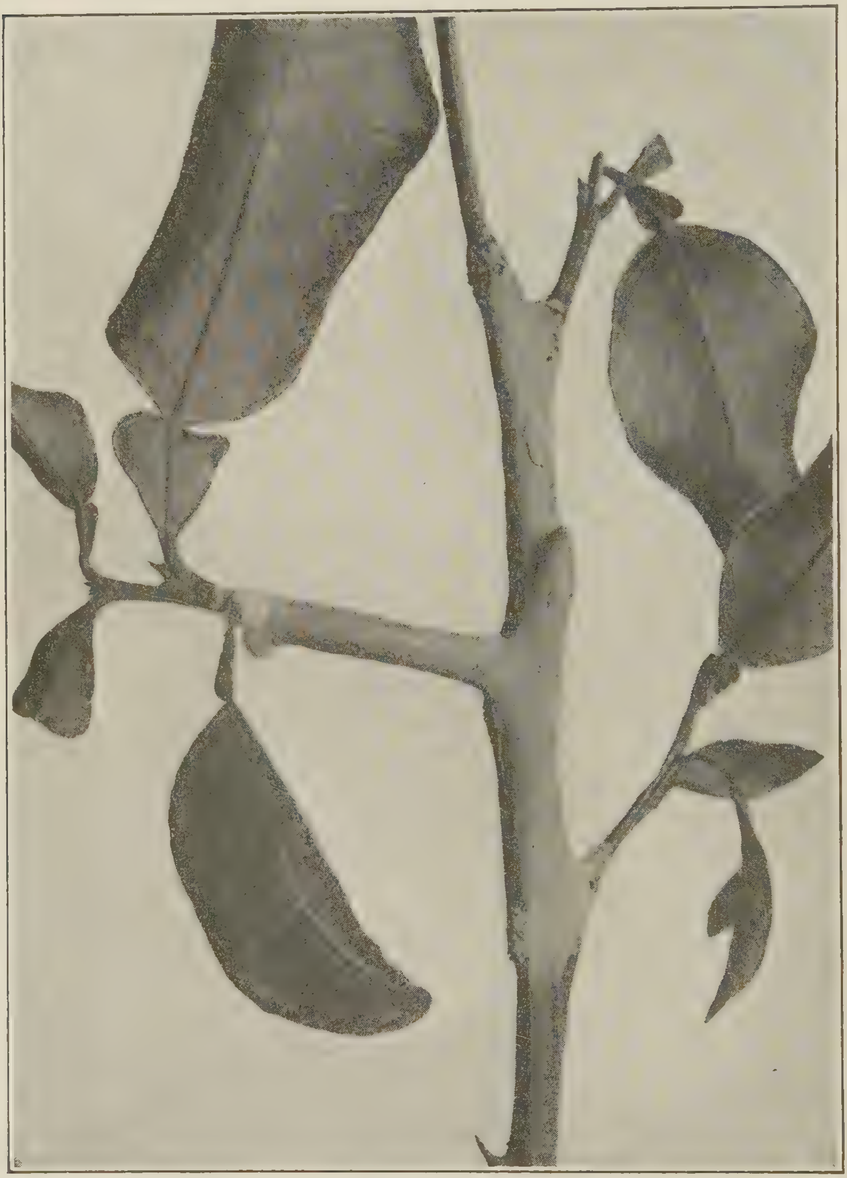

FIG. 77.—Septobasidium fungus enveloping the twigs of grapefruit in Florida. (*Fla. Agr. Exp. Sta.*)

normal and healthy. A species of scale insect, however, is found under this coating on the surface of the bark and probably lives in a symbiotic relation with the fungus. The fungus probably furnishes protection to the insects, while they, in turn, probably furnish secretions favorable to the growth of the fungus. P. H. Rolfs mentions in a letter the ocurrence of a similar Septobasidium in Brazil.

Characteristics of the Fungus.—The fungus *Septobasidium pseudopedicellatum* has been technically described by Burt (1916) as follows:

> Fructification resupinate, effused, coriaceous, dry, not separable from the substratum, varying from avellaneous and wood brown to cinnamon brown, the margin undulate, whitish; in structure, three layered, with (1) a layer next to the substratum of densely interwoven, thick walled, slightly colored, hyphæ 3μ in diameter, which form (2) a layer of erect, hyphal pillars, or pedicels, each about 500μ long, 20 to 40μ in diameter, about three to five to a millimeter, whose hyphæ spread apart at the upper end of the pillars, branch, and form and support (3) the hymenial crust about 300μ thick, with hyphæ loosely interwoven near the pillars, 3 to 3½μ in diameter, very dense at the outer surface with the hyphal branches or paraphyses 2μ in diameter, curved longitudinally along the surface and densely interwoven, erect probasidia nearly hyaline, rich in protoplasm, deeply staining, pyriform, 12 to 20 by 8 to 15μ, are borne laterally on the hyphæ about 15μ below the surface of the hymenium; spores white in a spore collection, simple, even, curved, 17 to 22 by 4 to 5μ, are borne singly from each of the upper three cells (so far as observed) of a straight or flexuous, few-celled, hyaline organ up to 60 by 5 to 5½μ, which grows from the probasidium and protrudes above the surface of the hymenium. *S. pseudopedicellatum* is the common Septobasidium of south eastern United States. It may be recognized by its brown, glabrous, shining, foliaceous crust which is raised and supported about a millimeter above the substratum on perpendicular, hyphal pillars which are as conspicuous as the rhizoids of a lichen. Old specimens may crack and break the hyphal pillars, and the hymenial crust curl outward so as to show the broken pillars attached to the under side (Fig. 78).

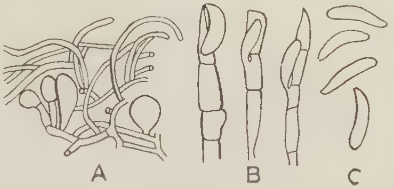

FIG. 78.—*Septobasidium pseudopedicellatum.* A, portion of the hymenium showing the longitudinally interwoven ends of paraphyses and some probasidia; B, three spore-bearing organs; C, spores ×360. (*After Burt*, 1916.)

The fungus has been collected not only on Citrus but on a wide variety of trees in eastern North America as well as the West Indies. Other species of Septobasidium or related fungi occurring on Citrus in a similar way are *S. bogoriense* Pat. (Gäumann 1922), *S. Acaciæ* Savada in Formosa (Tanaka 1918) and *S. albidum* Pat. in Formosa and Brazil (Tanaka 1918 and Hennings 1902).

Control.—The only control usually necessary for Septobasidium is to prune out the branches bearing the fungus. Under Florida conditions, the occurrence of the fungus is infrequent and injury is usually insignificant.

LICHENS ON LEAVES AND TWIGS

Lichens which belong to one of the lower forms of plant life, in which a fungus and an alga live together with mutual benefit to each other, are frequently seen on Citrus leaves and twigs as well as branches and trunks, especially in moist, damp, shady situations. They are not, as a rule, in the least parasitic, but live entirely on the surface and may be found growing also on rocks, fence posts, roofs of houses, etc. There are many varieties. A grayish to grayish-green form occurs occasionally on leaves in Florida and the West Indies, as circular to irregular spots (Fig. 79).

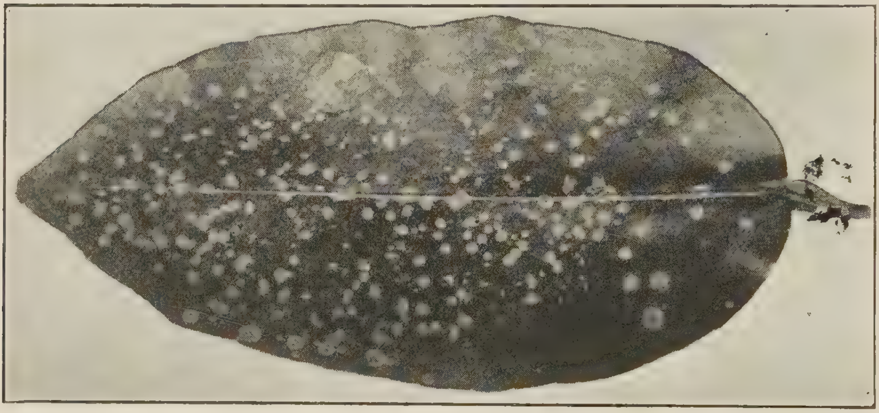

FIG. 79.—Lichens on Citrus leaves in Florida. (*After Stevens* (1918).)

Some of the grayish-green, paper-like, larger forms may also occasionally grow on leaves in damp, shady places.

These grayish-green lichens are often found on twigs, branches and trunk, very commonly in moist climates, and to some extent even under southern California conditions in places or seasons having considerable fogs and rains.

The lichens are considered harmless so far as any direct injury produced by their own growth is concerned. They obtain their own nutriment from the air, or from dead functionless tissues or organic matter on the surface. They are apt to be more abundant on twigs or branches of weak deteriorated trees than on vigorous, rapidly growing ones. For this reason their presence is sometimes mistaken for the cause of the bad condition of the tree, when in fact they are abundant merely because the tree is in an unthrifty condition from some other cause. When lichens become very abundant, however, they may be slightly harmful in an indirect way by harboring injurious insects, or by making conditions more suitable for the increase in parasitic fungi.

Control.—In general, the presence of lichens on the tree in moist situations need not cause any alarm. They are harmless in themselves. Trees have been observed in good, vigorous, healthy condition over a long period of years with lichens fairly abundant on their twigs. If the lichens increase because of lack of vigor of the tree from other causes, it is often better to use means for bringing the tree into vigorous growing condition than to incur the expense for getting rid of the lichens. Lichens may, however, at times become so abundant as to become troublesome and be somewhat harmful in an indirect way. In such cases they may be killed by spraying with Bordeaux mixture or with strong lime-sulfur solution. In case trees are being sparyed with lime-sulfur solution for insects each year, it is advisable to give the twigs, larger limbs and trunks an extra-heavy spraying at the same time. The solution should be allowed to drench very thoroughly the parts where the lichens are abundant. This may also be done when Bordeaux mixture or Bordeaux-oil emulsion is being used for some other purpose. By this practice it may not be necessary to spray separately for the purpose of ridding the trees of lichens alone. Bordeaux mixture will be more completely effective than lime sulfur in killing the lichens.

ALGA SPOT

A spot due to the partially parasitic alga, *Cephaleuros* (*virescens*) *mycoidea Karst* (*Mycoidea parasitica* Cunn.), has been reported on Citrus leaves and sometimes on twigs in south Florida and the West Indies. The damage from one or few spots is negligible, but when the spots become very abundant the leaves often weaken and fall off. It is usually of minor importance on Citrus (Earle and Rogers 1915, Fawcett 1915*a*, Stevens 1918*a*. Burger 1923*a*, Nowell 1923). It is parasitic on a large number of other plants in India and the East Indies as well as the Gulf states of the United States and the West Indies.

Other non-parasitic algæ sometimes become abundant on leaves and twigs during foggy and damp periods or in localities with high air humidities. They usually form a yellowish-green powdery coating of blotches. They do not appear to do any direct harm to the leaves.

Appearance.—The spots or patches due to the parasitic alga on twigs and leaves are slightly raised areas circular to irregular in outline, the surface covered with reddish-brown hair-like structures constituting the fruiting bodies. When these bodies are absent, the surfaces of older areas become greenish gray and velvety. If the affected twig is girdled, the bark is swollen and the twigs often enlarge at the affected parts. Only a few surface layers of cells are invaded. On leaves, circular round spots occur, reddish brown when covered with the hair-like outgrowths, and brownish to greenish brown when these are absent.

The Nature of the Alga.—This organism belongs to one of a very few groups of algæ, members of which show parasitic tendencies. It exists in various degrees of semiparasitism, from scarcely more than surface attachment, to a deeper penetration leading to cellular growths on both sides of the leaf and with possible connections between. After rains and periods of moist atmosphere, there occur outgrowths of dense, fine hairs bearing tiny globular heads. These are the sporangia, which, when ripe, on being moistened, discharge numerous motile spores. These spores, after an active period of swimming about in films of water, settle down and germinate.

Method of Attack.—The nature of the attack of this alga as it occurs on cocoa is described by Nowell (1923). It is probably the same for other plants. Twigs are apparently affected by the germinating of the zoöspores, which settle in slight surface cracks and develop during the formation of the first layers of bark. The alga invades some of the outer cortical cell tissue. Abnormal swelling of tissue frequently occurs. Where new bark cannot form fast enough to make up for the loss from the alga, death of twigs may result from severe attacks. Tissues attacked by the alga may also be a prey to certain fungi, such as Diplodia or the anthracnose fungus.

Contributing Conditions.—Lack of vigor of the host appears to be one of the most commonly observed conditions contributing to serious attacks of this alga, especially on the tea or cacao plant (Nowell 1923), and this same condition would probably favor the attack on Citrus or other trees. The weak, slow-growing twigs probably furnish a more favorable medium. This may be due in part to the fact that the bark is not being renewed so rapidly. A weakened condition of tree growth, due to lack of drainage or other unfavorable conditions, is a probable factor in the severity of the attack.

Control.—As indicated by the nature of the contributing conditions, keeping the trees in a vigorous growing condition should be an important preventive measure. Care in drainage, cultivation and fertilization to obtain the best vegetative growth should be exercised. Spraying with either Bordeaux mixture or with commercial lime sulfur appears to prevent the formation of alga spots effectively. In using Bordeaux mixture, where beneficial scale fungi may be present, Bordeaux oil emulsion (3-3-50 plus 1½ per cent of oil emulsion) should be employed (Chap. VI).

ATICHIA FUNGUS

A peculiar fungus belonging to the genus Atichia has been found in the West Indies, occurring superficially on lime leaves attached to the bodies of the purple scale. This fungus, which resembles in general appearance certain lichens, such as Collema, has a star-shaped body 4 to 5 millimeters in diameter (Fig. 80). The body is gelatinous and swells on the application of moisture. This fungus, which is now known as *Atichia dominicana*, has been described by Cotton (1914).

In structure, it resembles certain of the red algæ. It has branched moniliform filaments held together in a sort of mucilage, and in general structure is utterly unlike ordinary fungi. The structure of the thallus is either an irregular wart-like mass or a flattened branched body attached on its one side by a small central point (Fig. 80). The thallus is colorless within but black externally. Other species of this same genus occur on various plants, such as vanilla in Tahiti, Euonymus in France, coffee in Java and various plants in Central America and Chile.

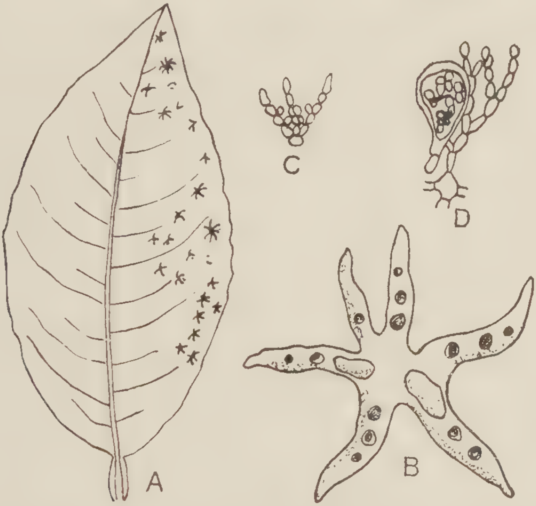

Fig. 80.—Atichia fungus: A, lime leaf with fungus; B, individual alga-like body (thallus) of the fungus ×9; C, a young propagulum of the fungus showing budding off of cells from three branches ×240; D, section through the thallus showing peripheral filaments and an ascus ×240. (*After Cotton* (1914).)

SCALE INSECTS AND WHITE FLIES

Scale Insects.—Scale insect is a term given to certain insects that have the ability to produce a scale-like covering, to form an epidermis which is hardened into a thick, firm chitinous wall or to secrete an abundance of white powdery or cotton-like wax as a covering (Essig 1915).

A large number of different scale insects may attack the fruit, leaves or branches of Citrus trees, some of them being especially numerous on the leaves and twigs, and others on the fruit. Some of their effects are not unlike that of certain fungus diseases. They often supplement or help open up the way for fungus diseases. They themselves are frequently attacked by fungi.

Scale insects are usually round, oval or elongated bodies, either sluggish or stationary and protruding from the surface when commonly observed. They vary in color as well as in shape, various varieties being red, yellow, black, gray and white. A majority of them secrete a sugary substance known as honeydew, in which the sooty-mold fungus thrives, producing a black coating over the surface of fruits, leaves and branches wherever this honeydew falls. It is also probable that this honeydew furnishes a good medium for the germination of spores and the growth of other fungi, some of which are parasitic. These scale insects do not usually produce definite lesions but have a serious effect upon the health of the tree.

Some of the more common and destructive of scale insects are the red scale (*Chrysomphalus aurantii* Mask.), black scale (*Saissetia oleæ* Bern.), purple scale (*Lepidosaphes beckii*), citricola scale (*Coccus citricola*) and mealy bugs (*Pseudococcus* spp.) in California; purple scale (*L. beckii*), long scale (*Lepidosaphes gloverii*), round scale (*Chrysomphalus aonidum*) and mealy bug (*Pseudococcus citri*) in Florida; yellow-colored scale (*Chrysomphalus dictyospermii*), chaff scale (*Parlatoria zizyphus*), purple scale (*L. beckii*), black scale (*S. oleæ*) and mealy bug (*Pseudococcus citri*) in the Mediterranean countries (Woglum 1913, Quayle 1914); purple scale (*L. beckii*), white scale (*Chionaspis citri*), large turtle-back scale (*Lecanium sp.*) and round scale (*C. aonidum*) in Cuba (Cook and Horne 1908); red scale (*C. aurantii*), purple scale (*L. beckii*) and circular purple scale in South Africa (Davis 1924); red scale (*C. aurantii*), white scale (*Chionaspis citri*), black scale (*S. oleæ*) and purple scale (*L. beckii*) in New South Wales, Australia (Froggatt and Gurney 1916).

Nature of Injury.—These scale insects feed by means of beaks or small mouth parts which are thrust through the epidermis into the tissues of the plant by which they suck out the juices. In addition to the actual loss of sap withdrawn from the plant tissue, many of them produce a toxic effect upon the plant itself. If the number of scale insects are not great, they may not have much effect upon the plant, but when they become numerous they weaken the tissue, making it a prey to various fungus diseases. In severe cases, they may even cause considerable death of the tissue attacked. In some cases, the effect is followed by gum formation on the twigs, as, for example, the attack of the red scale in California.

Control.—The control of various scale insects consists of three general methods, depending upon the variety of the scale and the conditions upon which they are being controlled: (1) spraying with oil or sulfur compounds, or a combination of these with each other or with other substances; (2) fumigation with hydrocyanic acid gas; and (3) the use of the natural enemies or parasites of the insects. These parasites may be other insects or fungi.

Fungus Parasites of Scale Insects.—The scale insects under humid conditions may be attacked by a number of different fungus parasites. In Florida, for example, the purple scale is attacked by four different fungi: the white fungus (*Fusarium aleyrodis*), the red-headed fungus (*Sphærostilbe aurantiicola*) (B. *et* Br.), the white-headed fungus (*Podonectria coccicola*), the black fungus (*Myriangium duriaei*) and sometimes by a fifth, the cinnamon fungus (*Verticillium heterocladum*). In the coastal regions of California, a species of Isaria is often found on the black scale. The entomogenous fungi, together with insect parasites, under quite favorable moist conditions in Florida keep this and other scale insects down so that they do little damage to the trees and fruit. During a dry season, however, generally during the winter and spring in higher, drier localities or regions exposed to winds, the fungi are unable to keep pace with the insects and often become very abundant and injurious unless the control by natural enemies is supplemented by spraying. Under drier climatic conditions, such as those in California, these scale insects are not apparently controlled to any appreciable extent by fungus parasites.

White Flies and the Fungi Parasitizing Them.—White flies in Florida hold the place in importance, that the black scale holds in southern California. Although there are eight species of white flies that may be found on Citrus in Florida (Watson 1918), three are especially important: the common (*Dialeurodes citri*), the cloudy winged (*D. citrifolii*) and the woolly (*Aleurothrixus howardii*).

Nature of the White Fly and Its Injury.—The Citrus white fly in its adult stage is a gnat-like insect. The eggs are laid upon the under side of the Citrus leaves and hatch into flat, scale-like larvæ, which suck the sap from the leaves. The injury to the tree is caused both by the sucking of the sap and by the black sooty-mold fungus (*Capnodium citri*) that grows in the secretion of honeydew from the white fly larvæ. When there is a bad infestation of this insect, the surface of the leaves, twigs and fruit become coated with a layer of the sooty-mold fungus in a manner similar to that following a very bad attack of black scale (*Saissetia oleæ* Bern.) or mealy bugs (*Pseudococcus citri* Risso.). This black sooty-mold coating on the leaves and fruit is the most conspicuous effect of this pest.

Parasitic Fungi on White Flies.—At least five different species of fungi have been found that are parasites of the Citrus white flies in Florida, namely, *Aschersonia aleyrodis* (Fig. 81), *Aschersonia goldiana*, *Ægerita webberi* (Fig. 83), *Fusarium aleyrodis*, and *Verticillium heterocladum* (Fawcett 1908*a*, 1910*a*). The first four of these are quite efficient in helping to keep the insect in check under favorable conditions of moisture and temperature. They attack the larvæ or scale-like stage of the white fly.

When the fungi become thoroughly established in a moist locality, the grower, without any other aid, usually counts, during average conditions, on one or two fairly clean crops in each three-year period. This is thought to be due to the fact that the fungi have become so abundant one year in three that the insects are nearly all killed. The following year the trees are practically clean because there are very few insects left. The fungi, however, having used up the food supply the year before, have become scarce. The few insects which remain increase rapidly and the next year become numerous enough to smut the fruit somewhat, and the second year so numerous as to smut the fruit badly, but by this time the fungus parasites have again increased to such an extent as nearly to exterminate the white-fly larvæ. The third year is, therefore, another year with few insects and clean fruit. If conditions are not normal, this three-year period may be changed to a shorter or longer period, depending largely on weather conditions. In some unusually moist situations the white fly may be practically controlled by the fungi for several years in succession without other aid. When a dry year occurs, the fungi are unable to keep the white flies in check. The fungi do most of their work in the rainy season and the insects multiply most in the dry season or during periods of lack of moisture.

A method of supplementing the natural distribution of the fungi by spraying the trees with water in which spores of these fungi have been placed has been in use for some years in Florida. This method was first brought out by Dr. E. W. Berger of the Florida Experiment Station.

Spraying with oil is also being generally used in controlling this insect. W. W. Yothers (1918*a*, *b*), of the Bureau of Entomology, has developed a heavy oil spray, an emulsion of lubricating oil in whale-oil soap, that is now being used against this pest and against scale insects as well. The work of the fungi is often supplemented by spraying at periods when the fungi are unable to keep the insect in check.

ENTOMOGENOUS FUNGI

Many fungi parasitic on Citrus insects produce pustules or other forms of growth on the surface of leaves, twigs and fruit which at first sight might be mistaken for harmful organisms, when, in fact, they are quite beneficial in helping to keep the insects in check. In moist localities in Florida, the West Indies and other countries, some of these fungi appear to constitute a large factor in preventing an excessive increase of scale insects and white flies. The principal species which have been found parasitizing Citrus insects will be mentioned and briefly described. For more special information regarding these forms reference may be made to publications by Parkin (1906), Fawcett (1908*a*), Rolfs and Fawcett (1913), South (1910*a*), Berger (1910, 1921), Morrill and Back (1912), Petch (1914*a*, 1921*a* and *b*, 1924) and bibliographies contained therein. The nomenclature of Petch is for the most part followed in this list.

Red Aschersonia, *A. aleyrodis* Webber (1897).—This fungus forms a raised, red to pinkish-buff pustule 1 to 1.5 millimeters in diameter on the surface of the leaf (Fig. 81). It is parasitic on larvæ of species of white flies in Florida, West Indies, India and Ceylon. The spores are immersed in cavities of the pustule and are about 9 to 14μ long and about 2 to 3μ broad. Following the discovery by Fawcett (1906, 1908*a*)

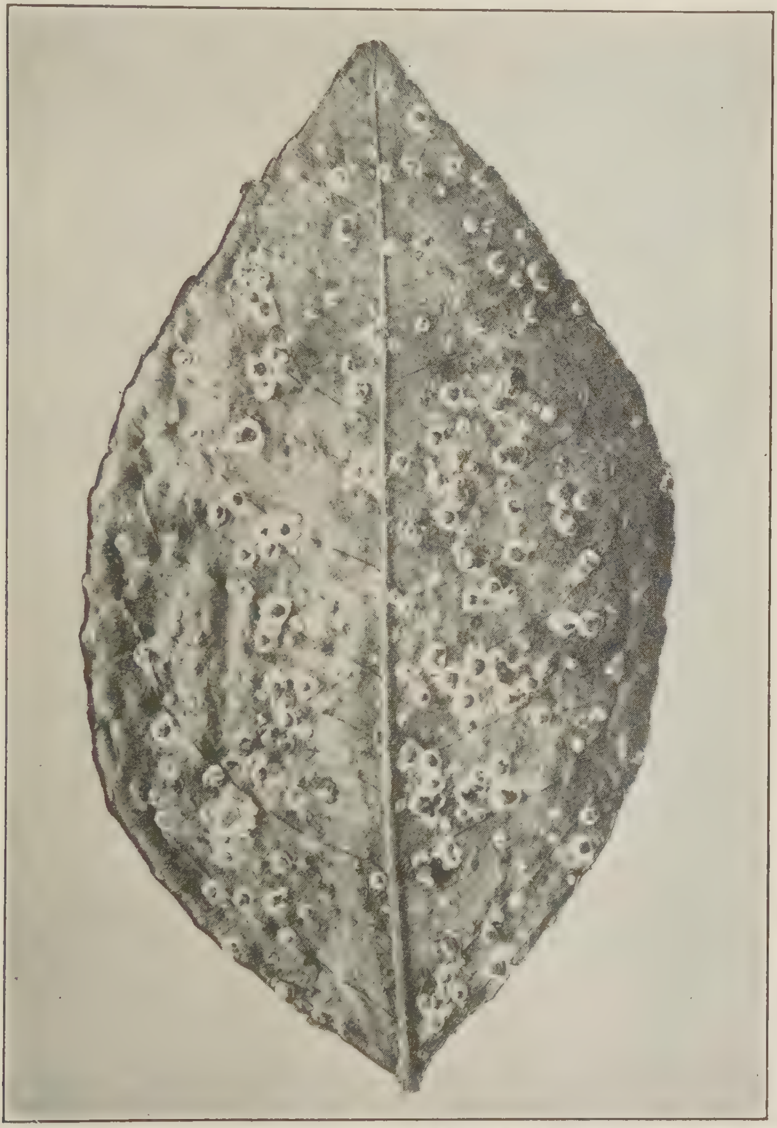

FIG. 81.—Red Aschersonia fungus (*Aschersonia aleyrodis*) which has parasitized whitefly larvae on Citrus leaf in Florida. (*Rolfs and Fawcett*, 1913.)

that this and other Aschersoniæ, could be readily grown in pure culture on sweet potato and other media containing sugar, a method of growing Aschersonia in large quantities on sterilized media in large bottles and distributing it on trees affected with white-fly larvæ in Florida has been perfected by Berger (1910, 1921).

Yellow Aschersonia, *Aschersonia goldiana,* Sacc. *et* Ellis.—This Aschersonia was formerly identified in Florida as *A. flavo citrina* P. Henn., but according to Petch (1921*a*) is not that species. It has pale-yellow to whitish pustules 2 to 5 millimeters in diameter on the leaves. This species appears to attack especially *Dialeurodes citrifolii* rather than other white-fly species. The spore cavities appear to be less sunken than in *Aschersonia aleyrodis* and the spores longer, about 12 to 15μ long and 2 to 3μ broad (Fawcett 1908*a*).

Turbinate Aschersonia, *Aschersonia turbinata* Berk.—This fungus has a perfect stage in *Hypocrella turbinata* (Berk.) Petch. It forms pink pustules about 1.5 millimeters broad and 1 millimeter high with a truncate upper surface, often concave. It is found attacking the wax scale, Ceroplastes, in Florida and the West Indies. This fungus has also been collected in Brazil.

Javanese Hypocrella, *Hypocrella javanica* (Penz. *et* Sacc.).—According to Petch (1921*a*), this fungus is the perfect stage of *Aschersonia coffeæ* P. Henn., *A. pediculoides* P. Henn., *A. eugeniæ* Kood and *A. suzukii* Miyabe and Sawada. It occurs on various insects and hosts but was found on the red scale, *Aspidiotus aurantii,* on *Citrus nobilis* in Formosa. The pustules are soft in the Aschersonia stage, becoming hard, orange or red brown, with yellow interior and about 5 millimeters in diameter.

Dark Globose Hypocrella, *Hypocrella reineckiana* P. Henn.—This fungus is found on Citrus in Ceylon and Formosa, on Lecanium and Parlatoria scales. According to Petch (1921), the following are imperfect stages of the same species: *Aschersonia marginata* E. *et* E., *A. sclerotioides* P. Henn., *A. pisiformis* Pat. The pustules are hemispherical or two-thirds globose and are up to 4 millimeters in diameter, at first pale yellow or buff, becoming slate colored and finally black.

Red-headed Fungus, *Sphærostilbe aurantiicola* (B. *et* Br.) Petch (*Sphærostilbe coccophila* Tul.).—This fungus attacks a large number of scale insects and has been reported in Florida, the West Indies, Ceylon, India, Madagascar, Japan, Formosa and Italy. Its perfect pustules (perithecia) are small, about 0.25 millimeter in diameter, subglobose, smooth, orange red to blood red. The imperfect pustules are clavate or flattened pulvinate in form, orange red to blood red in color, and about 2 millimeters high and 0.4 to 0.6 millimeter in diameter. On Citrus in Florida, it is an important fungus for keeping in check the purple scale, long scale and round scale (Fig. 82*A*).

Other species which have been found on Citrus insects, and which are similar in color and general appearance to the red-headed fungus, are *Sphærostilbe flammea* Tul. in Australia and *S. coccidophthora* (Zimm.)

Petch in Java (Petch 1921*b*). *Nectria diploa* B. *et* C. (*Microcera fujikuroi* Miy. *et* Sa.) also possess pustules somewhat similar in color and general appearance to the red-headed fungus and occurs on Citrus scale insects in Florida, Formosa and Australia.

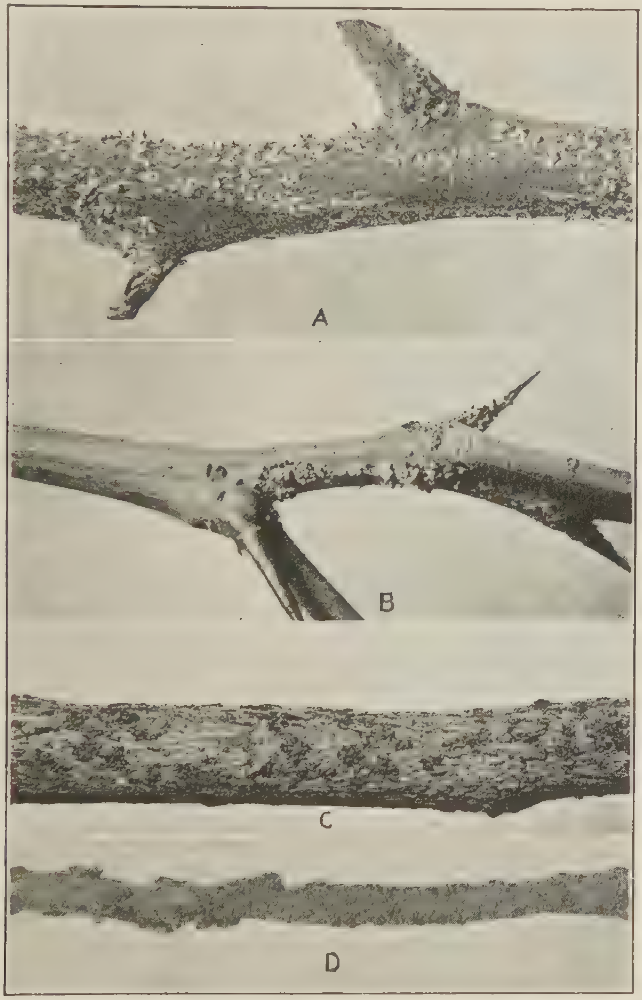

FIG. 82.—Entomogenous fungi which have parasitized scale insects on Citrus twigs. A, Red-headed fungus, *Sphaerostilbe aurantiicola;* B, White-headed fungus, *Podonectria coccicola;* C and D, imperfect and perfect stages of the black fungus, *Myrangium duriaei.* (*Rolfs and Fawcett*, 1913.)

White-headed Fungus, *Podonectria coccicola* (E. *et* E.) Petch (*Ophionectria coccicola*).—This fungus is also important in helping to keep down scale insects on Citrus in Florida and the West Indies, especially on the purple scale and long scale. It has also been found in Ceylon, Java, Formosa and South Africa. Its imperfect form consists of small white subconical heads mounted on cylindric or ovoid brown bases forming pustules 0.5 millimeter high and 0.4 millimeter in diameter. The perfect stage possesses pustules (perithecia) ovoid or subglobose, brown to dark brown, 0.6 millimeter high and 0.4 millimeter in diameter (Fig. 82*B*).

Other species which have been reported on Citrus insects and which are quite similar in appearance to the white-headed fungus are *Podonectria aurantii* (V. Höh) Petch (*Ophionectria tetraspora* Miyabe and Sawada) in Brazil and Formosa, *P. echinata* Petch (1921*b*) in Ceylon and *Microcera rectispora* (Cook and Massee) Petch in Australia.

Still other species which have a superficial resemblance to the white-headed fungus are *Nectria tuberculariæ* Petch (*Tubercularia coccicola* Stev.) with light-pink imperfect pustules and pale flesh-colored perfect pustules occurring on Citrus scale insects in Ceylon and in the West Indies, and *Nectria barbata* Petch with yellowish-brown pustules which occurs in Ceylon. *Lisea parlatoriæ* Zimm. has dark globose pustules 0.2 to 0.25 millimeter high and 0.15 to 0.18 millimeter in diameter, and has been noted in Java (Petch 1921*b*).

White-fringe Fungus, *Fusarium aleyrodis* Petch (1921) (*Microcera sp.* Fawcett 1908*a*).—This fungus presents a fringe of delicate white hyphæ growing outward from the edges of the larvæ. These hyphæ at first bear one-, two- or three-celled conidia, which are oval to fusiform in shape. Afterwards, there are formed on the edge of the larvæ pinkish spore masses, which are made up of a compact mass of lunate spores. The white-fringe fungus is found commonly on larvæ of the white fly in Florida. Another species of Fusarium, *F. epicoccum* McAlpine (1899) (*F. aspidioti* Sawada according to Petch 1921*b*), occurs on scale insects of Citrus in Australia, Formosa and Algeria.

The Black Fungus, *Myriangium duriæi* Mont.—This fungus appears to be widely distributed in tropical and subtropical regions of the world on many different kinds of scale insects (Petch 1924). It is an important parasite of Citrus scale insects in Florida, West Indies and some other Citrus countries. In Florida, it parasitizes the chaff scale, purple scale and long scale (Rolfs and Fawcett 1913). This fungus forms black carbonaceous crust-like pustules on the surface of scale-infested twigs, leaves or fruit. The pustules or stroma of this fungus vary in size up to 5 millimeters in diameter and are black or purple black and either shiny or dull. The individual apothecial tubercles are pulvinate to turbinate up to 0.7 millimeter high. Internally they are greenish white, becoming purple or purple black when mature (Fig. 82C, D).

Webber's Brown Fungus, *Ægerita webberi* Faw.—This fungus, whose vegetative form was first discovered by Webber (1897*a*) and the spore stage by Fawcett (1910*a*), is an important parasite of the white fly in Florida.

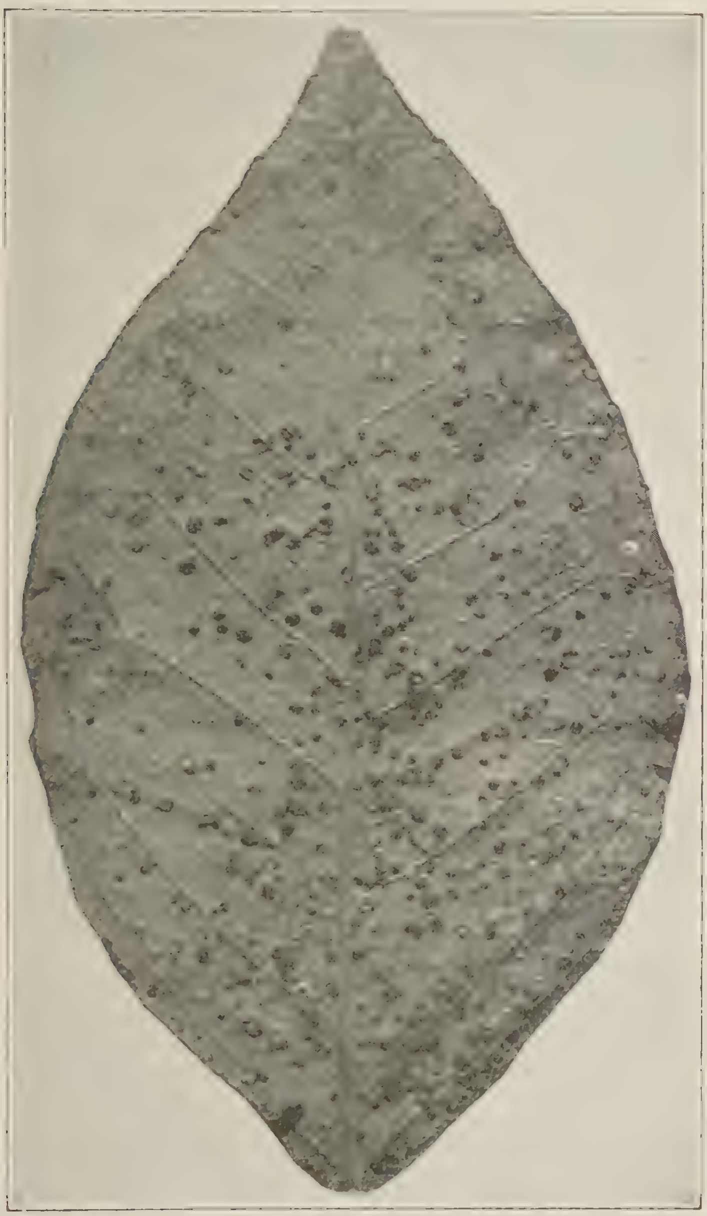

FIG. 83.—Citrus leaf showing pustules of Webber's brown fungus (*Aegerita webberi* of the white fly larvae in Florida. A few pustules of Red Aschersonia (lighter in the illustration) are seen on the right.

It has also been found in the West Indies, Ceylon and India. In its sterile form, it consists of a chocolate-brown compact stroma (Fig 83). From the margins of this stroma, there extend colorless thick-walled hyphæ. Later in the development of the fungus (usually in the summer or fall), the hyphæ at the margins of the stroma grow out long and colorless, extending not only over the undersurface of the leaf, but also around the edges and upon the upper surface. Sometimes the fungus extends down the petiole and along the stem to the next leaf, infecting every larva in its path. Sometimes the hyphæ become very abundant, and form silky grayish-brown strands that almost completely cover the leaf surface.

> On the upper surface of the leaf, on short lateral hyphæ, are borne the sporodochia, which are 60 to 90μ in diameter. These consist of an aggregation of conidia-like inflated spherical cells, 12 to 18μ in diameter. From near the place of attachment of the sporodochium, there radiate three to five hypha-like appendages, which are 150 to 200μ long by 6 to 8μ wide, and have one to three septa. This entire aggregation of spherical cells and appendages usually remains in union and functions as a spore. When abundant, these sporodochia present to the eye the appearance of a reddish-brown dust over the upper surface of the leaf. The presence of the brown stromata may be easily known at a distance of 10 to 20 feet by this characteristic appearance. In most cases, these sporodochia are found only on the upper surface, but if the lower surface of a leaf happens to be turned over for some time, they will develop there also. (Fawcett 1910*a*).

Cinnamon Fungus, *Verticillium heterocladum* Penz.—In general appearance, the compact hyphæ of this fungus resemble those of Webber's brown fungus, but on close examination they are strikingly different. The cinnamon-colored pustules are powdery on the surface and under the hand lens appear brush-like, bristling with hyphæ. The upright conidiophores produce either simple or compound whorls of branches containing the spores (Fawcett 1908*a*). This fungus occurs on a number of Citrus scale insects in Florida. It was first described by Penzig (1887) on *Lecanium hesperidum* on lemon leaves in Italy.

Cephalosporium Fungus, *Cephalosporium lecanii* Zimm.—This fungus is frequently found, especially on species of Lecanium. (Fawcett 1910*c*). Around and over the scale insects, a white or pale-yellow powdery bloom appears. This powdery or mealy appearance is due to the numerous minute heads or clusters of spores. It is common to scale insects on a number of hosts in the West Indies (South 1910). It is repórted on *Lecanium viride* on Citrus in Ceylon (Parkin 1906).

Mealy-bug Entomophthora, *Entomophthora fumosa* Speare.—This fungus according to Speare (1922) is the chief factor in the natural control of the Citrus mealy bug, *Pseudococcus citri*, in Florida. The disease is recognized in its early stage by a milky-white liquid which emerges from the crushed insect bodies. Spherical thin-walled "hyphal bodies" are seen in the liquid under the microscope.

"Isaria" Fungus of Black Scale.—In moister sections and in moist seasons in California near the coast, a white delicate powdery fungus frequently appears on the edges of and underneath the black-scale larvæ. This fungus has been known as "Isaria," though no true Isaria stage has been noted. It sometimes appears to attack the young under the scale covering. This fungus does not appear to thrive more than a few miles from the coast, and even there it appears to be an uncertain and variable factor (Quayle and Tylor 1915).

CHAPTER XIII

DEAD-SPOT DISEASES

PHYLLOSTICTA LEAF SPOT

This disease is not widespread, being known only in Japan, and is not of general occurrence even in that country. Where the disease does occur, however, whole trees are seriously defoliated, so that it is desirable to place the trouble on record in order to prevent its introduction into other countries. By analogy with instances of other introduced plant diseases, it is conceivable that this disease, if transferred to more favorable climatic conditions or more susceptible hosts, might be a much more destructive disease than it is at present. There appears to be no literature upon this disease in English or other occidental languages, although there is a brief mention of it in the Japanese book on Citrus diseases by Toji Nishida (1914).

Symptoms and Causal Fungus.—The disease appears on the older leaves approaching maturity, while the young newly formed leaves do not become immediately affected. The leaves first show light-colored, indefinitely defined areas which become larger and assume a brownish tinge. Surrounding such light-colored spots are similar indefinitely defined areas which are a darker green color than the normal leaf tissue and which have a watery appearance. These light-brown spots and the indefinitely outlined dark-green margins are very numerous, and all leaves of a certain degree of maturity on a particular tree may become so affected (Fig. 184). Affected leaves fall to the ground long before normal leaves are cast off, giving the tree a partially denuded appearance.

Japanese investigators have associated with this disease a fungus of the genus Phyllosticta. According to Hara (1917) (Tanaka, 1917), *Phyllosticta citricola* Hori causes what is known as the large, brown, round-spot disease on leaves. It is reported to have caused great injury to the Japanese summer orange in certain parts of Japan. It has also been reported on Satsumas. A similar leaf spot known as small, brown, round-spot disease was formerly considered to be due to *Phyllosticta curvarispora*, but by Hara, (1917) to a *Mycosphærella*. This fungus is found mostly on navels and Satsuma oranges. Various species of Phyllosticta have been found on Citrus leaves in other sections of the world, but their real relation to leaf spotting has never been adequately investigated.

Conditions Favoring the Disease.—Whereas most fungus diseases depend upon warm, moist weather for their development, this disease occurs towards the close of the growing season in Japan in late November and December. The weather in Japan during these months is very cold, although frequent rains occur. Although it seems probable that the disease is dependent on cold weather it might possibly be much more active if transported to a Citrus country of warmer temperatures.

Discussion.—Diseases caused by species of Phyllosticta are not ordinarily looked upon very seriously by plant pathologists. This leaf-drop disease as it occurs in Japan cannot be considered as very destructive, but its possibilities for injury in a more favorable climate or on more susceptible hosts should be considered.

A disease of similar appearance and pathological characters occurs on coffee, known as coffee blight, caused by the fungus *Hemileia vastatrix.* Although the fungus of coffee blight is not at all related to the Phyllosticta of Citrus leaves, it causes spots similar in character to the Phyllosticta spot on Citrus leaves. Coffee blight is so serious on Arabian coffee in the eastern tropics that in some countries commercial coffee production has been abandoned. The pathological nature of these Phyllosticta leaf spots, similar to those of coffee-blight lesions, and the similar dropping of the leaves lead to the feeling that entire exclusion of such a disease is much more economical than attempts to control it, once it becomes established in a new country.

PHYTOPHTHORA LEAF BLIGHT

In Western Australia, Carne (1924) has recently reported a leaf blight due to a fungus species of Phytophthora[1] probably related to *Phytophthora parasitica.* In addition to the attack on leaves, there is death of twigs and a decay of fruits. The disease was first noted in 1916. All varieties are attacked, but the fruits of the early varieties suffer most.

Symptoms.—Dark watery patches appear on the leaves, either on the edges or more especially toward the tips. Affected leaves curl and fall while still green. Almost complete defoliation may take place in severe attacks, especially on lemon trees. Usually, however, the defoliation is partial. Twigs are also killed, and frequently strips of bark of varying width are destroyed.

In Victoria, Australia, a similar effect originally thought to be due to the fungus *Pythiacystis citrophthora* was reported by Cole (1921). The disease occurred in a severe form following wet cool weather during the season from June to September. It attacked leaves, branches and fruit and was most severe about the time when the rind approached maturity. Oranges, navels, kumquats and mandarins were attacked, but lemons were reported to have been free though growing alongside the diseased orange trees. The fact that lemons appeared to be resistant would indicate that it was different from the Pythiacystis brown rot of California to which lemons are the most susceptible variety.

---

[1] As this goes to press we are in receipt of a publication from W. M. Carne describing the fungus as *Phytophthora hibernalis;* see Jour. Roy. Soc. W. Australia **12:** 13–41, Dec. 1925.

It is reported to produce dark blotches or spots on the leaves. The foliage and the twigs near the ground are the first to become affected, from which the disease spreads upwards throughout the tree. Trees with dense foliage are most severely attacked. The first appearance is a semitransparent spot similar to that immediately following a heavy frost. The leaves soon fall and irregular brown blotches appear on the twigs. The beginning spots on the fruit are described as having a greasy appearance with enlarged oil cells. A sticky substance may appear on the diseased twigs and the fruit soon fall off. A condition similar to that of collar rot was also noted.

Contributing Conditions.—Since leaf blight is due to the attack of a soil-inhabiting fungus, *Phytophthora sp.*, related to *Phytophthora parasitica* and *Pythiactystis citrophthora*, it is very dependent on moisture conditions. In western Australia, as reported by Carne, it appears after the first soaking rain in autumn and recurs with every wet spell till it usually reaches a maximum in severity in August. It ceases in dry weather. Trees nearest to permanent water or those on the wettest soils or on land flooded by streams suffer most from this disease. Like Pythiacystis (p. 373), the spores of this fungus are splashed or blown to the lower leaves and fruit. It is then flecked by the wind-blown branches to higher levels in the tree.

Control.—Spraying with Bordeaux mixture 4-4-50 or Burgundy mixture 4-6-50 during the last part of April or early in May is suggested by Carne as a means of control. He also suggests picking up fallen fruit and destroying it. The recommendations by Cole for control of the disease in Victoria is to prune off the low-hanging branches, destroy the diseased fruits and spray with Bordeaux mixture.

CHOCOLATE SPOT

This disease,[1] which occurs in the Delta region of Egypt, produces a spot on both leaves and fruit. The symptoms on the leaves appear as a felt-like brown or chocolate-colored mass more or less circular in form and 2 to 3 millimeters in diameter (Fig. 84). This mass is loosely fixed to the leaf in the early stages and can be easily removed, leaving a slightly pale spot.

On the fruit, owing to the rough surface of the rind, the chocolate-colored mass is more adherent. As the season advances, the tissue of the leaf is killed under the place where the felty mass was located, leaving a dead circular spot. The spots on the leaves do not enlarge beyond the size of the felty mass, but the spots on the fruits enlarge as the fruits grow and the spot becomes deeper until it frequently occupies the entire thickness of the rind (Fig. 84). The fruit at maturity may become deformed, depending on the size and number of the spots.

---

[1] This account and illustrations of the disease were furnished through the kindness of T. Fahmy of the Botanical and Plant Breeding Section of the Ministry of Agriculture, El Giza, Egypt.

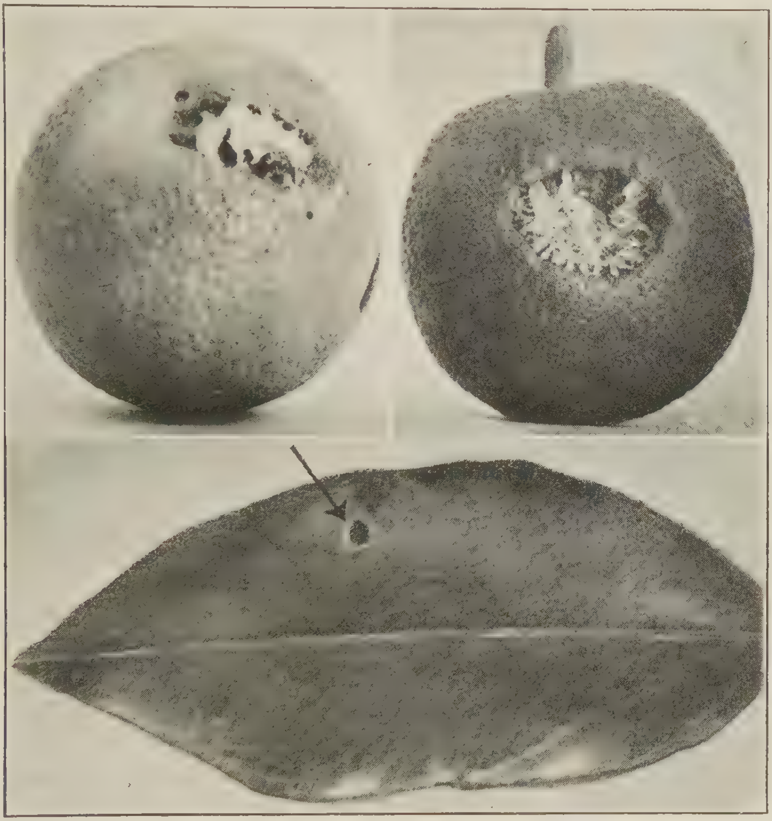

Fig. 84.—Chocolate spot of Egypt, indicating effects on orange fruits and leaf. (*Photo contributed by T. Fayhm.*)

A microscopic examination of the chocolate-colored felty mass shows it to consist mostly of the growth of a species of Alternaria, together with Cladosporium and sometimes Penicillium. Spraying with 1 per cent Bordeaux mixture (4-4-50) was found to be an efficient preventive of the disease.

FROST INJURY TO LEAVES AND TWIGS

The severity of frost injury to leaves and twigs will depend much upon the condition of maturity as well as other factors. Most often, frost injury occurs while the tissues are fairly mature during the dormant season, but if frost comes unusually early or late or after a warm winter, the foliage may be in an active condition and very susceptible to injury.

Symptoms.—When the frost injury is severe and the tissue of the entire leaf and twigs is killed, they will wither, blacken and die back. If the weather is moist, many kinds of saprophytic fungi, such as Cladosporium, Alternaria, etc., will enter the tissue and it will become covered with black, moldy growth. If the injury is less severe, part of the leaves and twigs may be killed, while others will remain alive; and in still other cases of light frost a portion of the tissue of the leaf blades may be killed while other portions remain alive. When the tips of the blades or other localized parts are killed, the dead areas are often mistaken for diseases due to organisms (Fig. 85).

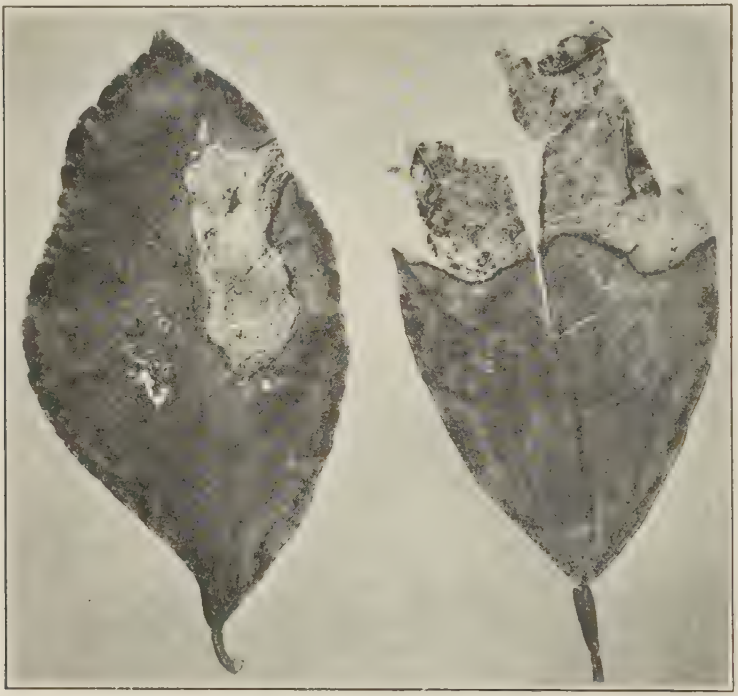

Fig. 85.—One type of frost injury to leaves, in the dead portion of which saprophytic fungi have developed.

In other cases, the effect of the frost may be so slight as not to kill any portion of the blades, but merely some of the surface cells. These surface effects become brown and corky or may result in gum spots or vitreous-like hard layers on the surface (Fig. 73). A light white frost on the surface of the leaves in the early morning, followed quickly by bright sunshine, may often result in effects of this kind. These frost injuries to leaves and twigs may open up the way for various disease-producing organisms, such as *Sclerotinia libertiana, Botrytis cinerea* and Diplodia, which cause twig blights. In years when there is frost injury, the Citrus blast appears to be more severe than at other times. It is thought that the chilling of the tissue, even when it is not completely killed, renders it much more susceptible to the attack of the Citrus-blast organism.

Frost injury frequently has a relation to such diseases as melanose, anthracnose and Diplodia twig blight, because the organisms in connection with these diseases live and produce an abundance of spores in the dead twigs. Frost injury to the trunk is discussed in Chap. X and to the fruit in Chap. XVII.

FUMIGATION AND SPRAY INJURY

Fumigation and spraying may cause several types of injury to leaves and twigs, some of which are frequently mistaken for the effects of fungus diseases. If the leaves and twigs are not fully mature, they may be killed back by fumigation with cyanide in a manner similar to that caused by frost or a fire too near the tree. Where the leaves and twigs are mature, various types of spotting may occur. Certain definite areas of the leaf may be killed, or if the injury is very slight, it may result merely in a scab-like surface or in inducing gum spots quite similar to those produced by a slight frost injury.

One of the factors that has been found greatly to favor injury from fumigation is the previous spraying of the foliage with Bordeaux mixture. If Bordeaux mixture has been applied, very severe dropping of the leaves and even defoliation may take place (Fig. 86).

One type of spray injury to the leaves may be shown by burnt spots, where the tissue of the blade is entirely killed. Another type is caused by concentration of the spray material, producing an injury to the surface layers only, resulting in a hard crust or vitreous layer. Sometimes another form of spray injury may be seen as very minute dots imitating the effect of certain fungi. An example of this is the injury following spraying with Bordeaux, which is known as stellate melanose (p. 228).

MISCELLANEOUS LEAF SPOTS

Spots on leaves are produced by a number of different agencies, and the primary cause is often difficult to determine, especially if some time has elapsed since the cause or set of causes was operative. It is frequently true that diverse agencies may produce similar or almost identical effects. A number of different causes for spotting have already been mentioned and the nature of the spots described. Some of the most important of these spots are due to various fungus and insect attacks fumigation, spraying injury, sunburning, frost, etc. Some others, usually of minor

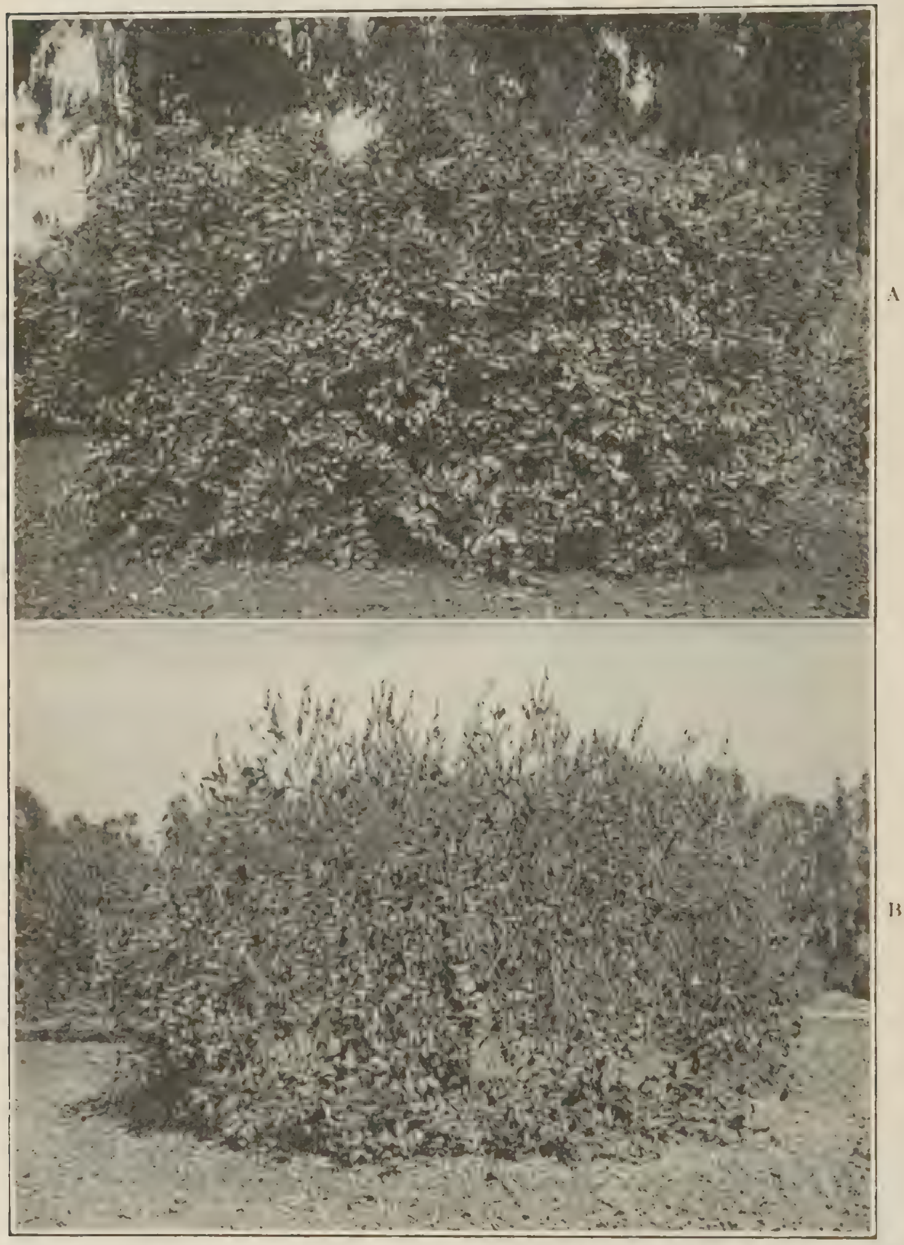

FIG. 86.—Injury to foliage of lemon fumigated with hydro-cyanic acid gas following spraying with Bordeaux mixture. A, tree sprayed one year or more before fumigation; B, tree sprayed several months before fumigation. (*After Woglum* (1920).)

importance, will be mentioned here. More research is necessary to determine by inoculation experiments the true relation of some of these organisms supposed to be responsible for the spots.

Cercospora Spots.—Spots supposed to be due to different species of Cercospora have been mentioned by several authors. A fungus described as *Cercospora fumosa* is mentioned by Penzig (1887) as occurring on Citrus leaves in Italy. Dark-brown spots 5 to 10 millimeters in diameter are reported by Hara (1918) in Japan on the variety known as summer orange. In 1908 we noted a spot associated with the occurrence of Cercospora in Florida with spores similar to those described as *C. fumosa* by Penzig. Stevens (1918*a*) also mentions a spot of the same kind described as round to oval in shape, dark brown to black, and appearing on both sides of the leaf. The spots on the upper surface of the leaf are also described frequently as smooth and covered by a silvery membrane. On older spots, a dark, fuzzy, distinct surface growth of the fungus is mentioned.

Mycosphærella Leaf Spot.—A spot supposed to be due to *Mycosphærella loefgreni* has been described by Noack (1900) in Brazil. Another species, *M. lageniformis*, was described by Rehm (1911) as occurring on orange leaves in California. In Brazil, these are found on leaves, young twigs and thorns and even on unripe fruits. The spots on leaves in Brazil are from 1 to 5 millimeters in diameter, round or elliptical in shape and of a raw flesh color, gradually becoming yellowish tan. The tissue affected finally becomes white and the diseased tissues dry out. A sharp dark-brown margin surrounds the spot. The spots on the twigs and thorns are always one sided, and their longest extension is in the direction of the axis of the twigs.

Alternaria, Macrosporium and Pleospora.—Spots on leaves due to species of Alternaria, Macrosporium and Pleospora, all closely related fungi, have also been mentioned from time to time. We have frequently found spots on Citrus leaves in Florida and California which were invaded by fungi with spores characteristic of one or another of these genera, but there has always been uncertainty as to what part these fungi played in producing the spots. It has been generally assumed by us that the tissue was first weakened or killed by some other agency and that these were largely secondary. Further investigation is needed in this field. A species of Macrosporium on leaves has been mentioned by McAlpine (1899) in Australia and by Doidge (1924*a*) in South Africa. A leaf spot supposed to be due also to a species of Macrosporium has been noted by Bal (1920) as occurring on citron in India. This fungus is said to attack first the margin and middle of the leaf. The leaves turn yellow and curl, the center of the spot becomes white and the leaves drop. A leaf spot in which a Pleospora is associated is mentioned by R. E. and E. H. Smith (1911) as abundant in the northern part of California. In Australia and South Africa, *Pleospora disrupta* McAlp. is thought to be associated with leaf spots.

Stigminose.—Another leaf spot mentioned by Stevens (1918) as occurring in Florida is suspected to be the result of punctures from the pumpkin bug, Nezara. It is a small round brown spot, hard and glazed in appearance, usually on the upper surface but sometimes penetrating the leaf tissue. The spots vary from ⅛ to ⅜ inch in diameter. A small depression as if the leaf had been punctured is usually found at the center of this spot, and the margin is surrounded by a pale narrow band.

CHAPTER XIV

DISEASES RESULTING IN DEATH OF ENTIRE PARTS

ANTHRACNOSE OF TWIGS AND LEAVES, INCLUDING WITHERTIP AND BLOSSOM BLIGHT

Anthracnose is a term generally employed by plant pathologists to designate the effects produced by fungi of the genus Glœosporium, Colletotrichum or other closely related organisms. In Citrus, the term is used for effects of *Glœsporium limetticolum* Clausen, *Colletotrichum glœosporioides* Penz or *G. foliicolum* Nishida. The fungus *G. limetticolum* is parasitic on the young leaves, twigs and fruit of the lime, *Citrus aurantifolia;* the fungus *G. foliicolum* affects only the Satsuma- and mandarin-orange varieties, *C. nobilis*, while certain strains of the other fungus, *Colletotrichum glœosporioides*, usually attack only the mature, weakened leaves, twigs and fruit of oranges, lemons, grapefruit and other Citrus trees.

ANTHRACNOSE OF LIME

In southern Florida, Cuba and the West Indian islands, this disease, due to *G. limetticolum*, frequently causes serious damage to the growing twigs, leaves and fruit of the Mexican or West Indian lime, *C. aurantifolia*. So far as known, the fungus responsible for this type of anthracnose does not attack in the same manner any other variety of Citrus tree. The dying back and withering of the young twigs is suggestive of the term withertip, and the blighting of buds and flowers suggest blossom blight.

History and Distribution.—It is uncertain where anthracnose of the lime first originated. What appears to be this disease was mentioned by Swingle and Webber (1896), who considered it to be related to verrucosis or scab. Their statement is as follows:

> Scab, or a disease closely allied to it, occurs in very young fruit of the lime, and in some localities is often so severe as to destroy the crop entirely. For example, a grove in tropical Florida capable of yielding 500 boxes of fruit annually, when attacked by this disease, produced for several years only a few hundred fruits, and a majority of these fell off while still young.

Rolfs (1904) refers to anthracnose of the lime as a severe disease, affecting the blossoms, buds, young fruit, young twigs and leaves. It was also mentioned as an important disease in Cuba by Cook and Horne (1908). While anthracnose of the lime has been common in some of the West Indian islands for a long time, this form of the disease on limes was apparently absent in certain of the islands between Trinidad and Porto Rico until about 1922, when it appeared and rapidly spread in Dominica (Nowell 1923). Heavy losses are also noted as occurring in British Guiana, and in Trinidad in 1918, where it is reported to have put a stop in the lime-growing industry of the colony there. It has also appeared in Tobago. Except as mentioned by Pope (1923) in Hawaii, so far as known, it has not been reported on limes in regions outside of North America, including the West Indies.[1] It has not been found on limes in California.

In a large series of inoculation tests, including all of the commercial groups as well as related Citrus varieties, carried out in the orchard and greenhouse, Fulton (1925) found strong indication that only the West Indian lime was highly susceptible. All others were immune in the field tests and only certain citrons showed doubtfully slight susceptibility when punctured in the greenhouse.

Symptoms.—The fungus attacks young shoots, leaves and fruits while they are still tender. After the leaves and twigs are nearly mature or after the fruit has reached approximately ¾ inch in diameter, the tissues are immune to further attack. The infected twigs wither and shrivel at the tips for a distance of an inch to several inches. They are sometimes ringed or girdled by an attack farther back, fall over and hang lifeless as if attacked by some insect. Frequently, the lifeless portion falls away with formation of gum at the wound. Young leaves which are sometimes infected but not entirely killed back may have dead areas on the margins or tips with distortion of the remaining portions as further growth takes place during maturity (Fig. 87). Unopened buds, when attacked, may fail to develop, the petals turn brown and the buds fall off without opening. In the opened blossom, the stigmatic surface of the pistil is commonly attacked, causing the fruit to drop or to become worthless. Fruits that are attacked but not shed show lesions varying from scab-like spots to deep canker-like areas over half or more of the surface. Consequently, the disease may easily be mistaken for scab or verrucosis. Such fruit is usually deformed and worthless (Fig. 169).

Causal Agent.—Anthracnose of the lime is brought about by the fungus *Glœosporium limetticolum.* The fungus was distinguished by Clausen (1912) from *Col-*

---

[1] Certain phases of anthracnose on lime fruits are similar to and readily mistaken for scab. Since recent observations and experiments in Florida and the West Indies indicate that the West Indian limes are apparently immune to scab, the question is raised as to whether previous observations indicating the occurrence of scab on limes in South China and Java may not be lime anthracnose or some other similar disease. It is now known that the early occurrence of anthracnose on limes in Florida was thought to be scab or a disease closely allied to it. It is of interest in this connection that in recent studies by Jenkins (1925) the scab fungus has been definitely shown to be a Sphaceloma, which is an allied genus to Glœosporium.

letotrichum glœosporioides Penz, which it closely resembles in general form. It has been found to be virulent on the lime, but not on other Citrus varieties. The differences between this lime fungus and the other as given by Clausen are mainly as follows: *G. limetticolum* produces no setæ, the acervuli are always flesh colored or salmon pink, while the other may be dark or black on dead leaves and twigs. The conidiopheres

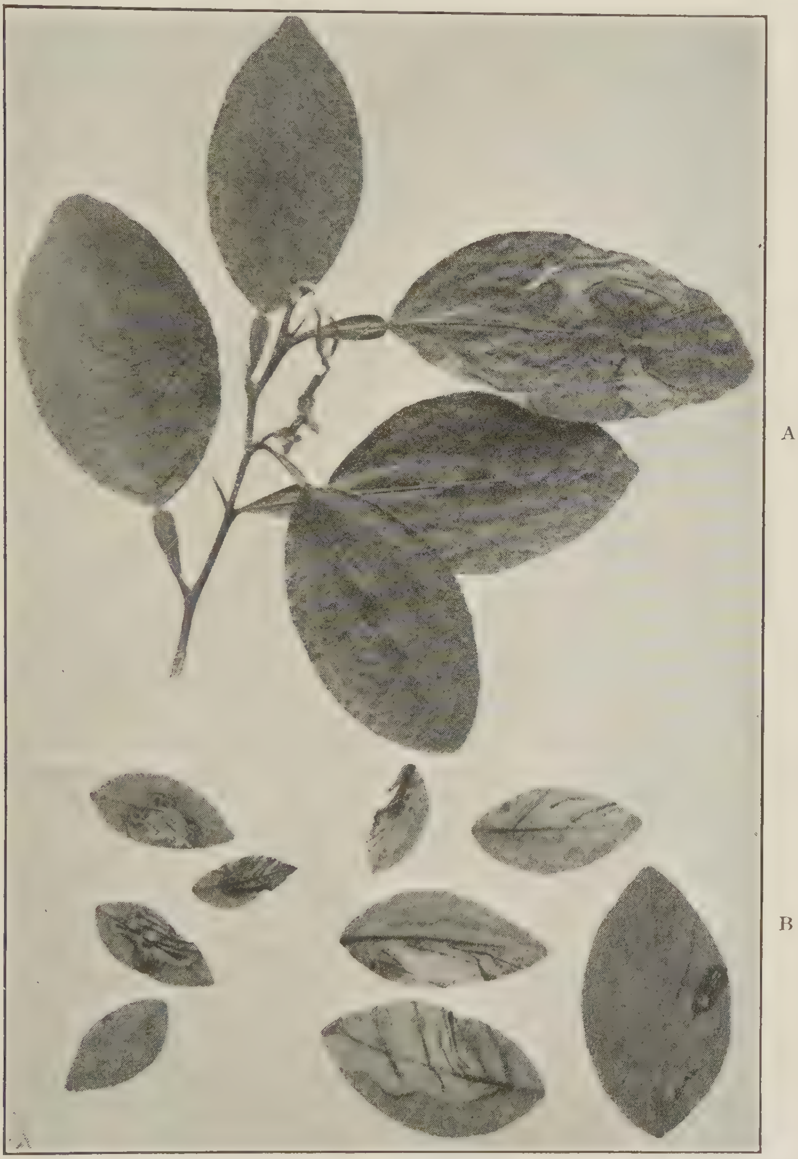

Fig. 87.—Anthracnose of lime, due to *Gloeosporium limetticolum.* A, specimen placed in herbarium 40 days after inoculation. (*After Clausen*, 1912.) B, six days after inoculation. (*Photo by R. E. Clausen.*)

of the lime fungus are hyaline throughout their entire length and arise from a loose stroma of hyaline hyphæ, while the conidiophores of the other are pale, sooty at their bases and arise from a more compact stroma. In cultures the lime parasite does not form black stromatic pellicles. The conidial spores are more pointed at both ends and less likely to be constricted, and when fresh are markedly less granular, and have a less distinct nucleus than *C. glœosporioides* (Fig. 88). The measurements of the lime fungus *G. limetticolum*, as given by Clausen, are as follows: acervuli 50 to 100μ in diameter, conidiophores 16 to 30 by 3 to 5μ and spores 12 to 20 by 3.5 to 6μ. For *C. glœosporioides* the measurements given by Rolfs (1904) are: acervuli 90 to 270μ, setæ 60 to 160μ, conidiophores 3 by 18μ and spores 10 to 16 by 5 to 7μ. Burger (1921), however, has shown that the variability in spores of different strains of this latter fungus are so great that such measurements as given above are probably useless in themselves for distinguishing these two forms. The mean length of a hundred spores each of eight different strains of *C. glœosporioides* varied from 11.5 to 20.3μ and the mean width of the same strains varied from 3.3 to 6.4μ. In California, Burger also found, on species other than limes, strains of this fungus that retained their white mycelial growth throughout as does the parasitic lime fungus.

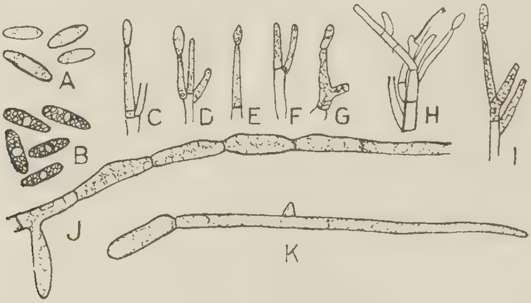

FIG. 88.—A, spores of *Gloeosporium limetticolum;* B, spores of *Colletotrichum gloeosporioides;* C to I, conidiophores or spore-bearing hyphae of *Gl. limetticolum;* J, K, hyphae formed by germination of spores of *Gl. limetticolum;* magnified 400 diameters. (*After Clausen* (1912).)

Contributing Conditions.—Weather conditions, especially sufficient moisture for the germination of the spores, is an important contributing condition. As in melanose and scab, only young tissues are susceptible, mature tissues being immune. It is probable that the fungus *G. limetticolum*, like *C. glœosporioides*, lives over from year to year in dead twigs and that the presence of these as sources of infection is also a contributing factor. Fulton (1925) points out that dew drip or rain is an important condition in connection with the occurrence of anthracnose of lime. It is also likely that driving rain storms with wind are also important factors in dissemination of the fungus. Insects may also be an important means of dissemination.

Control.—The control of anthracnose of the lime may be effected only by protecting the new growth and developing fruit by either Bordeaux mixture or lime sulfur. Certain difficulties arise, however, because in some countries the flushes of new leaves and twigs and the blossoming of the lime may be somewhat scattered. As Nowell (1923) points out, however, there are "fairly well marked times of maximum production" which are somewhat constant for a particular locality, and if spraying is done at these times, it may be possible to save a large proportion of the fruit. In experiments by Fulton, referred to by Nowell, it has been shown that a spray schedule, carefully carried out at time of blooming and early setting, may successfully control the disease. In a general way, two or three later applications at intervals from one to two weeks may be necessary. For the first spraying, Bordeaux-oil emulsion (3-3-50 plus 1 per cent of oil) is advisable and for later spraying lime sulfur 1 to 30 to 1 to 40. If the spray is used on the young tender fruit, it is advisable to reduce the oil content to one-half of 1 per cent. Under severe conditions of anthracnose, Fulton writes that it may be necessary for complete control to use Bordeaux-oil emulsion (3-3-50 plus one half of 1 per cent of oil in the form of emulsion) at intervals of one to two weeks while the young fruits are forming. Close watch must be kept for signs of increase of scale insects which may have to be controlled later by straight oil emulsion.

The fact that susceptibility to this anthracnose is closely restricted to the West Indian lime (including the Dominica Thornless) gives promise, as Fulton (1925) points out, of ultimately substituting other types of lime as a means of complete control. A wide range of immune varieties is available also as a basis for attaining immunity by hybridization with the present West Indian lime.

In some countries, discretion in the use of fertilizers and irrigation may also aid in minimizing the disease. Since the fungus development is favored by damp, moist, humid weather, applications of nitrogen fertilizers, which will stimulate the susceptible new succulent growth, should be applied at such a time, if this be possible, as to bring out new growth in a dry rather than a moist period.

ANTHRACNOSE OF ORANGE, LEMON, GRAPEFRUIT. ETC. (WITHERTIP)

The dying back of mature or nearly mature twigs, the spotting of mature leaves and the spotting of mature fruits may, under certain conditions, be attributed, in part at least, to certain strains of the fungus known as *Colletotrichum glœosporioides.* In many respects, this fungus resembles closely the lime anthracnose fungus. Clausen (1912) separated the lime fungus from the other and described the former as *Glœosporium limetticolum.* It seems highly probable that on Citrus there exist strains or forms of the *C. glœosporioides* fungus, some of which are merely saprophytic and others of which are semiparasitic. Burger (1921) found that this species of fungus was quite variable.

Strains of the fungus are almost universally present on dead twigs or dead tissue of Citrus and even on the surface of live twigs and leaves in healthy as well as diseased trees in Florida. Even in some of the drier sections of California, strains of this fungus are common at certain seasons on dead twigs or functionless tissue without doing serious harm. In general, this fungus, *C. glœosporioides*, attacks only the twigs or leaves that have been previously weakened by unfavorable soil or climatic conditions. For this reason, there has been much difference of opinion among investigators and growers as to the part played by the organism, in any given outbreak known as anthracnose or withertip of this type. Fawcett (1915*a*) believes that some of the severest injury in connection with anthracnose or withertip of oranges and grapefruit in Florida may be due to the combined effect of the anthracnose fungus and other fungi, such as *Diplodia natalensis* and *Phomopsis citri* (p. 37). Both of these fungi have been found capable of injuring Citrus trees when placed in cuts in branches, and they are also found abundantly in branches along with *C. glœosporioides.* Inoculations showed that in combination the fungi are capable of doing more damage than when acting alone (Fawcett 1913*a*). As to the anthracnose on the lime previously described, there has never been any doubt as to the parasitic nature of the organism involved, since it attacked young growing tissue, and not the mature tissue.

History and Distribution—Although most attention has been called to anthracnose or withertip in Florida, especially by the publication by Rolfs (1904), this same effect has been reported in nearly all Citrus-growing countries. Strains of the organism, so similar that they are not capable of being distinguished one from the other, have been found to have a world-wide distribution.

One of the most severe cases of anthracnose in California was that in Ventura County reported by Essig (1911). It has also been studied in California by Barrett (1915*a*). During the summer of 1924, a severe attack in the Corona section came to the attention of the Citrus Experiment Station. It was confined almost entirely to the Mediterranean Sweet variety of orange. Spots developed rapidly on the leaves, in which the fungus appeared to be the active agent in the destruction of tissue. Small twigs were also killed back rapidly. Many trees were partially or nearly defoliated. Other varieties of orange at that time were not seriously injured, nor were lemons or grapefruit. A study was made to determine whether this strain of fungus was strikingly different from the ordinary strains in culture media, but no diagnostic difference was detected. It was found to be capable of inducing typical anthracnose spots (p. 459), when introduced into pricks on mature orange fruits.

Another outbreak occurred on tangerine orange trees in the San Gabriel Valley, California, in the fall, winter and spring of 1924–1925, apparently due to a strain of the anthracnose fungus which did not severely attack other commercial Citrus species growing in the same section at that time. Cold weather was probably a contributing factor, but was not, in itself, the cause of the slow and extensive death of twigs and the decay of fruit.

Symptoms.—The appearance of anthracnose (withertip) on the leaves, twigs and branches has the following general characteristics:

On leaves, nearly or quite mature, spots occur, light green at first, soon turning brown. If the air is moist, the fruiting bodies (acervuli) soon appear as mere dots, and pinkish masses of spores ooze out on the surface. These are easily seen with the hand lens and may develop on either surface of the spot, or, if the air is very dry, may not show at all until the leaves are placed in a moist chamber. Sometimes the fruiting bodies appear like black dots or pustules pushing through the epidermis. The spots may be at the margins or tips of the leaf blades and more rarely near the midrib (Fig. 89). In California, the fungus is often found invading the tissue at the tips of leaves on lemon trees suffering from malnutrition.

On branches of oranges, lemons, etc. (not limes), anthracnose is characterized by the dying back of mature twigs. The dying back is usually slow and the leaves drop off, but in some cases it may be sufficiently rapid to cause leaves to wither and dry up before abscission has taken place. In most cases attributed to withertip, the symptoms are the appearance of numerous small dead twigs, often accompanied by dying or sickly twigs from which the leaves have already fallen. Larger branches in severe cases appear sickly, turn yellowish, shed their leaves and die back. Trees in this condition usually drop their fruit (for symptoms on fruits, see p. 454). The symptoms here mentioned for anthracnose of twigs may also be brought on by unfavorable conditions of climate or soil. Lack of sufficient water or nutrition or the presence of injurious salts in the soil may produce effects scarcely distinguishable from those attributed to anthracnose. If the anthracnose fungus is present, as it usually is at least under Florida and California conditions, the fungus is likely to propagate rapidly in the weakened tissues. For this reason, it is difficult to distinguish between injury initiated by the organism and that initiated by unfavorable conditions alone, after which the fungus has come in to play a saprophytic or semisaprophytic rôle. In such a disease, it is not safe to conclude from the mere presence of the organism that it is responsible for a given effect.

Characteristics of the Fungus.—On twigs or leaves or even on dead bark of the trunk, the fruiting bodies (acervuli) of this fungus are frequently seen, as small dark dots or raised pustules (Fig. 89). When mature, especially in moist air, it is possible, with a hand lens, to see a break in the epidermis under which a mass of spores is located within the acervulus. Around the margin of the acervulus will frequently be seen dark-colored stiff hairs, the setæ. These are not always present,

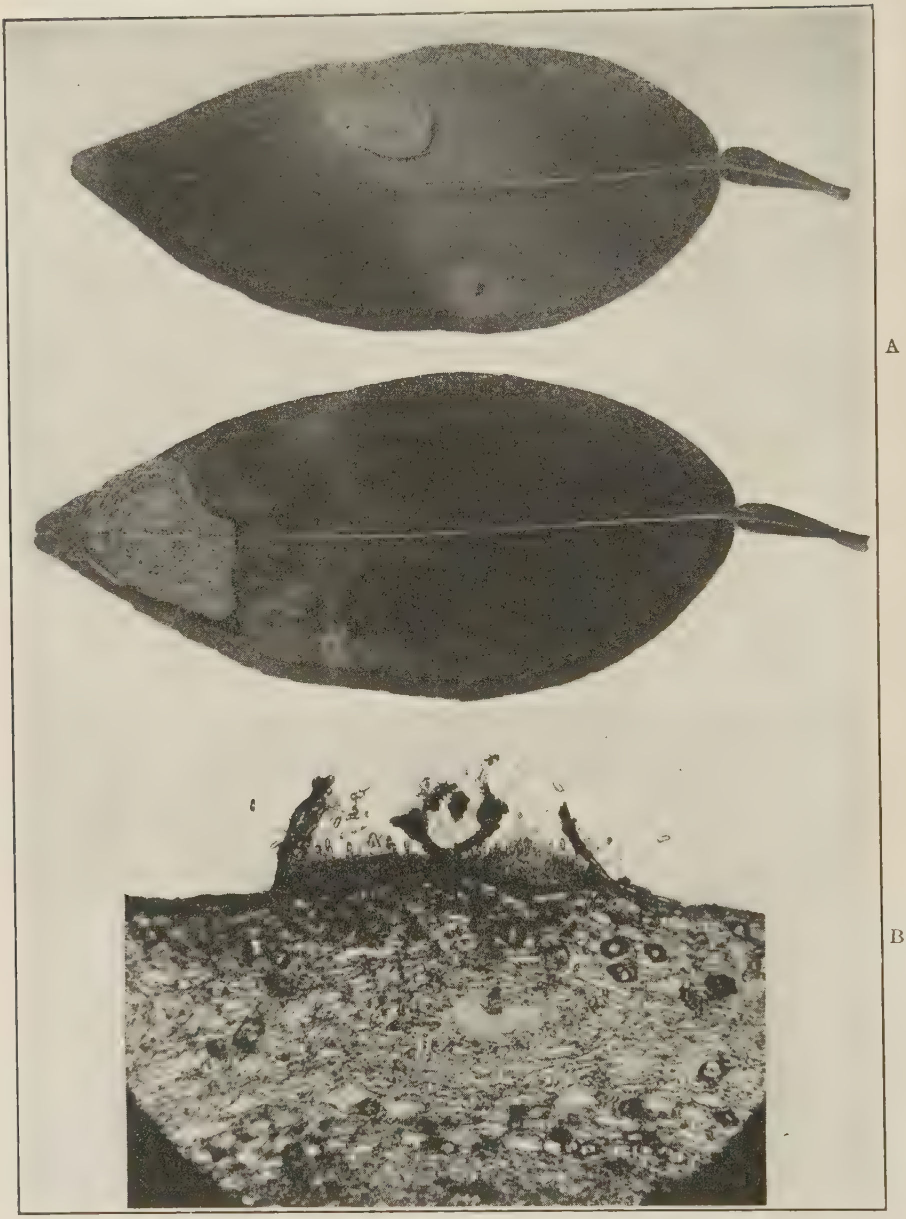

FIG. 89.—A, anthracnose spots on grapefruit leaves; B, cross section through fruiting body or acervulus of the anthracnose fungus, *Colletotrichum gloeosporioides*, on surface of twig magnified about 200 diameters, showing the ruptured epidermis and spores within and outside the acervulus. (*Photos contributed by J. T. Barrett.*)

however. The acervuli and spores are often innumerable and may occur on every dead twig or piece of dead tissue throughout the tree. Under California conditions, the fungus is abundant on dead twigs in the coast regions, but not so prevalent at all times in all of the interior, drier and hotter sections. During certain seasons or certain years, it is possible to find dead twigs free from the fungus in the San Joaquin or Imperial valleys or in Arizona, but this would rarely be true near the coast nor in Florida. In fact, almost any live Citrus twig in Florida, when put into a moist chamber, shows a growth of this species of fungus as soon as it begins to deteriorate on standing. In our experience in Florida, it was difficult to free even the most healthy-looking orange leaves from the presence of this fungus by sterilizing the surfaces with mercuric chloride. In a majority of cases, such leaves when placed in culture tubes would finally show, on standing, abundant spores of *Colletotrichum glœosporioides.*

Rolf's (1904) description of the fungus, which in part includes references also to the form on lime, is as follows:

> Acervuli located on the surface of the leaf, twig or fruit; 90 to 270μ in diameter, erumpent, superficial. Shape various, not uniform, occurring on either surface of Citrus leaves; disposed irregularly or in more or less concentric lines; pale to dark colored. On tender lime twigs, tender lemon twigs, lemon fruits and lime fruits, pale colored, dull red in masses, confluent. Epidermis breaks irregularly. Setæ fuliginous, ranging in length from 60 to 160μ, frequently once or twice septate, disposed at margin of acervuli; frequently absent, and on tender lime twigs, tender lemon twigs, lemon fruits and lime fruits usually absent.
>
> Conidia broadly oval or oblong, 10 to 16 by 5 to 7μ, hyaline; size variable in same acervulus, usually with one or two oil drops. Developing from a well-defined stroma; basidia, 3 to 18μ. In moist chambers the conidia stream from the break in the epidermis. Intrabasidial setæ, variable 8 to 30μ by 3 to 6μ, cylindrical or sometimes enlarged at distal end; hyaline. Penzig's measurements are 18 to 25 by 4 to 5μ for the basidia and 16 to 18 by 4 to 6μ for the spores.

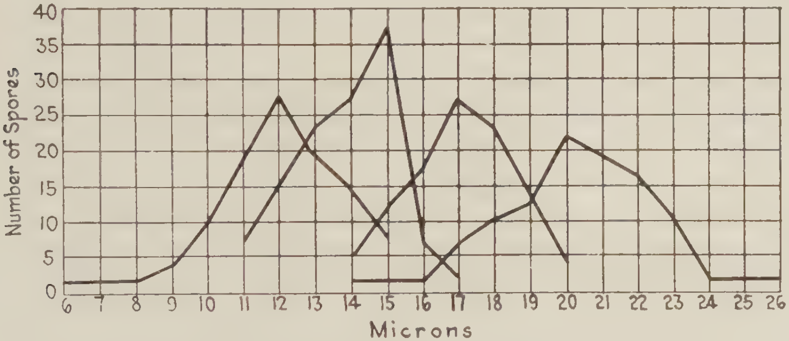

FIG. 90.—Variability of four strains of the anthracnose fungus *Colletotrichum gloeosporioides* in spore length. (*After Burger* (1921).)

There is strong evidence in Burger's (1921) investigations that this fungus is extremely variable and that it is a "polymorphic species made up of a number of strains," that it is subject to being changed in its growth habits by environmental conditions and that frequent mutations arise when grown on culture media. Burger found great variation between California strains in amount and color of mycelium, quantity of spore production, and the length and width of spores. He showed that some strains failed to remain constant as to these characters when grown for a long time in the laboratory. As an example of variation in strains grown under identical conditions, the length and width of 100 spores of each of eight strains were measured. The mean length varied from 11.5 to 20.3μ, while the width varies from 3.2 to 6.4μ. The variability of four strains is graphically shown in Fig. 90. The supposed differences between *C. glœosporioides* Penz and *G. limetticolum* are given on page 286 and Fig. 88.

Contributing Conditions.—The most important contributing conditions for the development of anthracnose (withertip) of oranges, lemons, etc. of the type under consideration are those which have to do with the weakening of the tissues, such as unfavorable nutritional conditions in the soil and injurious environmental conditions. Lack of sufficient water, lack of proper plant food, toxic salts in the soil, winds, extremes of temperature, moisture and the like are some of the most important factors. Trees injured by gum disease, gophers, drought or other influences that cause them to lose their vitality are apt to show symptoms of anthracnose.

Control.—Since anthracnose of this type depends to such an extent on conditions contributing to the weakness of the tree and the tissues, it is of first importance to keep up the health and vitality of the trees by the proper care as to fertilizing and other orchard practices. Strong, vigorous trees, even under unfavorable weather conditions that are beyond the owners' control, are more likely to remain resistant and immune to the anthracnose fungus, even though it be ever present.

If the trees begin to show serious symptoms of the disease, considerable pruning may be necessary in order to bring them back. Trees may have been weakened by drought, too low or too high temperatures, excessive winds or other factors largely beyond the growers' control. Such trees, besides showing the direct effect of these environmental conditions, are apt to become susceptible to further inroads from the presence of the anthracnose and other accompanying organisms previously mentioned.

In such cases, especially in Florida, rather drastic pruning may sometimes be necessary. When pruning, care should be taken to make smooth cuts, usually at the base of a branch or limb, so as not to leave any projecting stubs in which infection is likely to start again. After pruning, the larger cut surfaces should be painted with a good disinfectant or suitable paint (Chap. VI). The grove should be given good care after a severe pruning of this kind. It should receive good but not too much fertilizing, in order to bring about a strong healthy growth that will be more resistant to further attacks of the fungus.

Anthracnose of the Satsuma Orange

In addition to the withertip or anthracnose of limes and the withertip of sweet oranges and grapefruits which are caused by closely related fungi, there is a similar disease of Satsuma oranges in Japan which is caused by a fungus *Glœosporium foliicolum.* This disease is not definitely recorded outside of Japan, although there is a disease of similar character on mandarin-orange fruits in Australia which might be suspected as identical to the Japanese Satsuma disease.

The symptoms on fruit are described under Fruit Diseases (p. 462). It occurs also very commonly on the young actively growing leaves during May and June in Japan, causing a leaf spot. The fallen leaves show watery, cloudy spots on which there appear bright-red pustules which are the acervuli of the fungus. Young, newly formed twigs are also attacked, becoming first a yellowish-brown color and finally a dead black.

The causal relation of the fungus to this anthracnose on Satsuma has been shown by inoculation experiments by Hemmi (1921) on leaves and by Lee (1923*a*) on fruits.

A full discussion of the causal agent, contributing conditions and prevention will be found on page 463 under Fruit Diseases.

CITRUS BLAST FORM OF CITRO-NECROSIS

The Citrus blast is a disease primarily of the leaves and twigs. Its causal relation to a bacterial organism, *Bacterium citriputeale,* was shown by Lee (1917). Blast usually begins at a fresh break or injury to the wing of the petiole and involves the petiole, base of the leaf blade and a portion of the twig surrounding the base of the petiole. It may, at times, start in injuries at other points of the leaf or twig. The same organism that initiates blast is also responsible for black pit on fruits, discussed under Fruit Diseases (p. 443).

History and Distribution.—When Hodgson first called attention to this disease in northern California in 1912 (Hodgson 1917*a*) and Coit (1916) described it under the name of Citrus blast, it was thought to be a new disease confined to northern California. Lee (1917) isolated the organism and proved by a series of inoculation experiments its causal relation to the lesions. He found the disease distributed throughout northern California and also observed it in Tulare County in 1916, a year of unusually heavy rainfall. It has since been found in nearly all localities of California where Citrus is grown, and was shown by Fawcett to be due to the same organism as that causing black pit (Fawcett, Horne and Camp 1921, 1923). The black pit had previously been described by C. O. Smith (1913).

The same or a very similar disease producing lesions identical with blast and black pit was seen by Fawcett (1925) in Sicily and Italy in 1923. Attention was later called to a publication by Savastano (1921), in which the latter had pointed out the similarity of this Sicilian disease to Citrus blast. Savastano further stated that the disease had been present in Sicily and Italy for a long time. It was considered to be a minor disease until recent years. Later, after the causal relation between blast and black pit was known, a more detailed publication by Savastano (1923) gave the history, distribution and description of the disease. Savastano believes that in Sicily the organism not only affects the leaves, twigs and fruit but also the base of the trunk and roots. He is of the opinion that this is probably the same organism that was imperfectly identified by Comes as *Bacillus gummis*. As far as known, the disease has not been reported in any other Citrus countries, except California and Italy.[1] Another disease somewhat like Citrus blast in its effect on twigs and fruit is the bacterial disease of South Africa (p. 450).

Symptoms and Development.—Citro-necrosis occurs in two forms, one on the leaves and twigs and the other on the fruit. Under California conditions, its activity is confined to a limited period, usually extending over six to eight weeks in the winter and spring. Oranges and grapefruit are probably the most susceptible to the injury upon the leaves and twigs, while lemons are the most susceptible so far as the fruit is concerned.

The most striking characteristic of the blast manifestation is an area shading from brown to black, which usually starts in a break or torn place on the wing of the petiole (Figs. 91 and 92) and extends rapidly in both directions to the base of the leaf blade and to the twig surrounding the base of the petiole. During cool, damp weather, these areas enlarge rapidly, but when the dry and warmer weather comes on, the progress of the lesions is checked. The following features are to be noted as the lesions stop enlarging: there is a definite line between the dead and live tissue; new callus tissue forms under the affected areas; the surface of the affected bark becomes dry; and the initial brown to black color changes to a reddish brown, forming scabs (Figs. 91 and 92). The colors on Ridgway's (1912) chart are chestnut brown, mummy brown for the newer lesions and auburn, chestnut or mahogany red for the older on the twigs. The stained or superficially marked areas on leaf blades not killed are buckthorn brown, cinnamon brown to ochraceous tawny.

If the disease progresses very rapidly, the leaves wither and die while still attached to the tree, but if its progress is slow or if it occurs in a somewhat warmer temperature, an abscission layer is formed and the leaves are shed. In the latter case, it seldom progresses farther than the

---

[1] See occurrence also in Australia, p. 446.

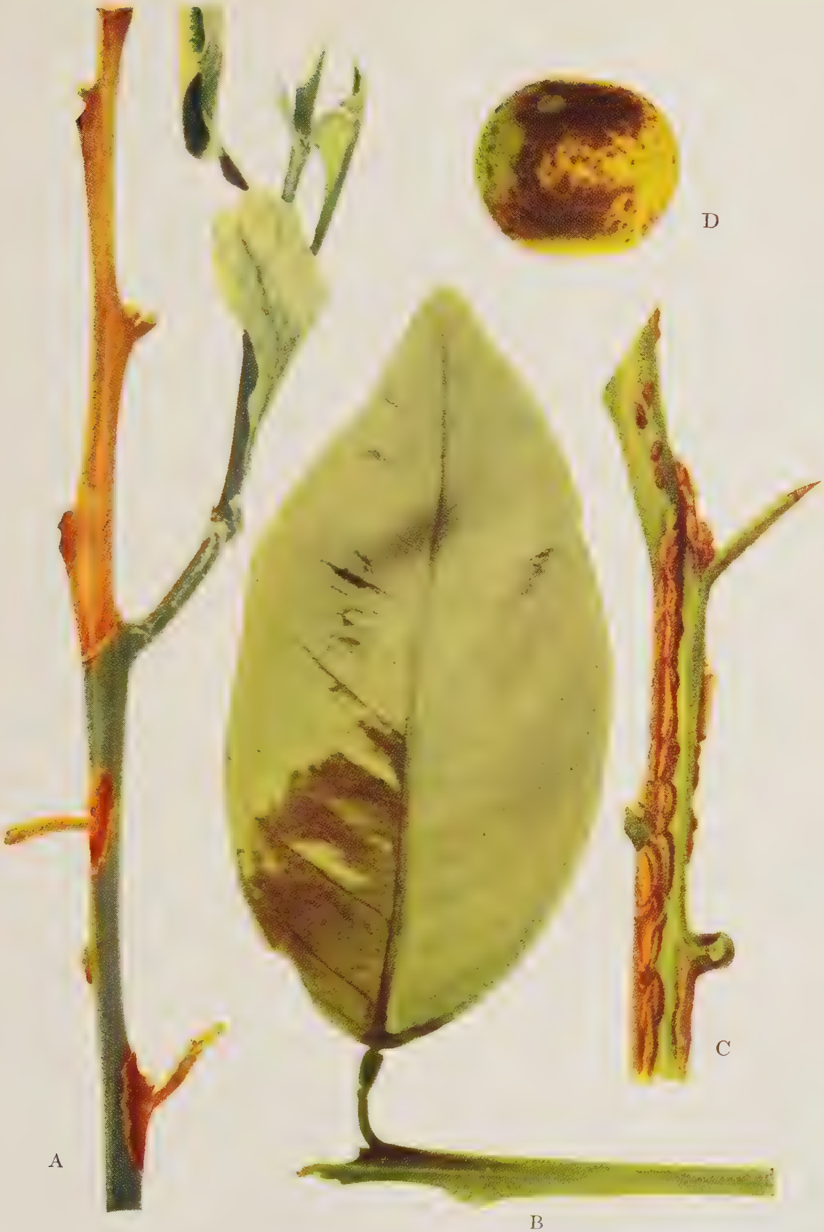

FIG. 91.—Citrus-blast and exanthema on orange. A, Showing the end of a twig killed back and Citrus-blast lesions at the bases of petioles, in summer after the disease has become inactive. B, Citrus blast on leaf and stem in an active stage in February, California. C, Excrescences of exanthema on twig. (*After Swingle and Webber* (1896)). D, Young orange fruit with exanthema markings. (For exanthema see also Fig. 188.)

(*Facing page* 294)

petiole of the leaf, and few lesions will be formed on the branches. In very severe cases, the disease may progress so rapidly as to girdle the twigs and cause many of them to wither and die; but more frequently the lesions are checked before girdling takes place. Microscopic exam-

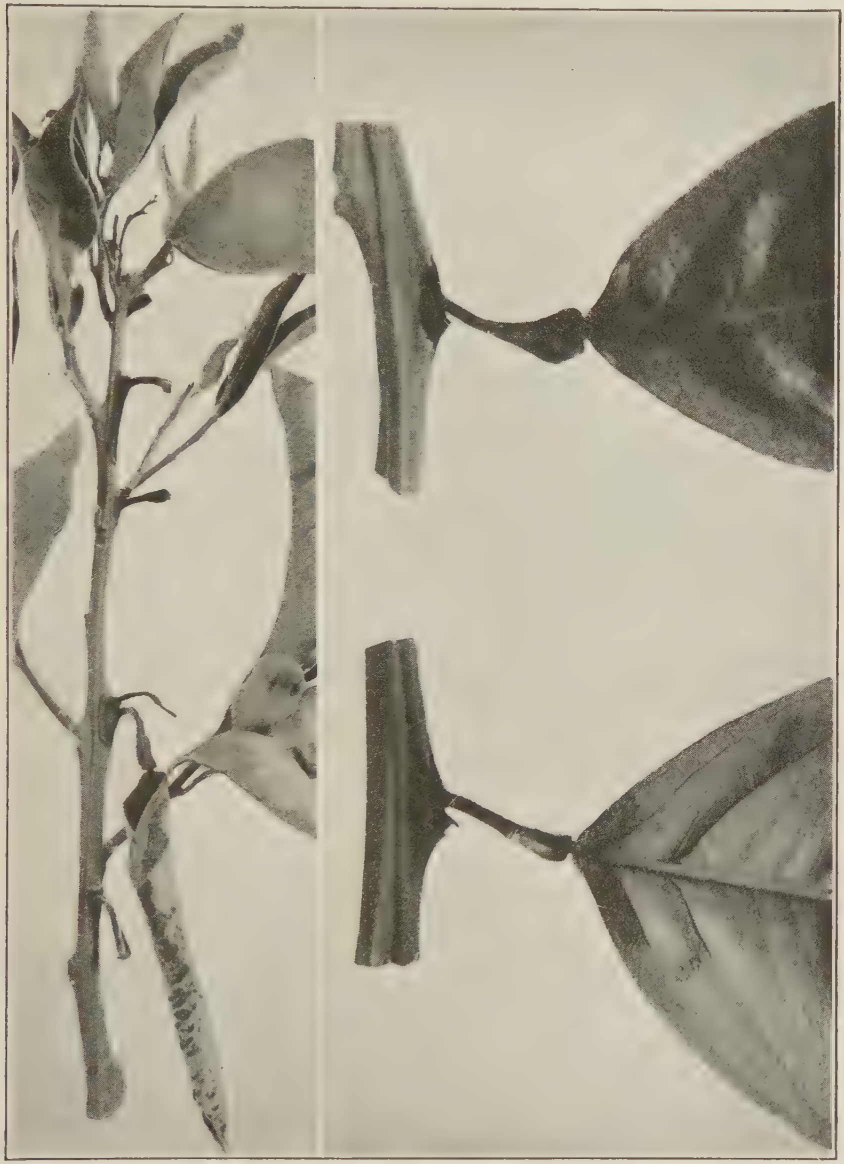

FIG. 92.—Citrus blast on twigs and leaves of orange. Showing development of lesions on the petiole, base of the leaf blade and on the twigs, and one leaf dried, rolled and still firmly attached.

inations have shown that the bacteria are most abundant in the layers not far from the cambium. They appear to attack the parenchyma tissue principally, and do not kill the woody tissue except in extreme cases (Fig. 93).

A corky-brown scorching or staining of the surface layers of leaves often accompanies the blast. This sometimes spreads over a portion of the leaf blade beyond the edge of the lesion (Fig. 91). The occurrence of this staining under the same conditions as those which produce blast has indicated that the Citrus-blast organism may have some relation to it. It differs from the ordinary form of blast in that only the very outermost layers of cells are affected, while the affection does not cause the death of the tissue beneath. Some experiments have shown that a reddish-brown scorching similar to that observed can be produced by rubbing the under surface of the leaves with a blunt instrument and

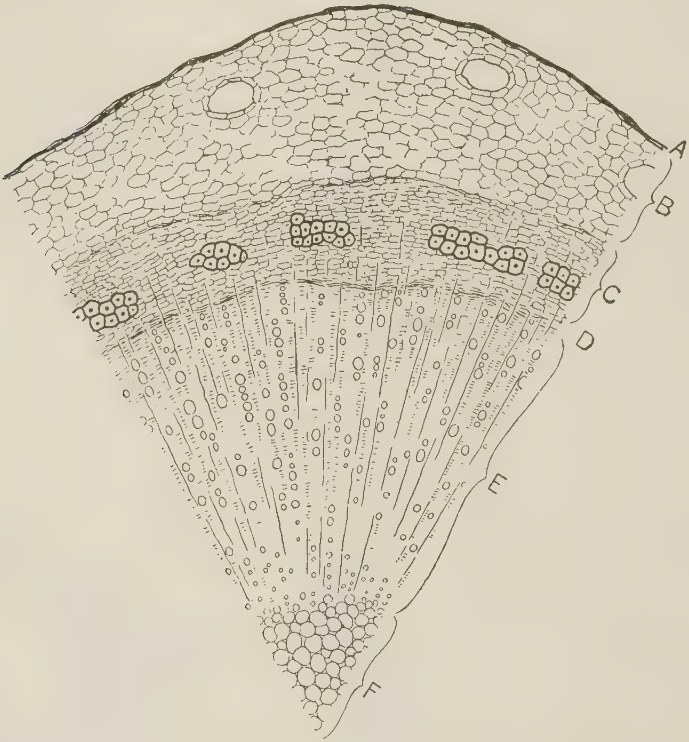

FIG. 93.—Diagramatic sketch of cross section through an initial blast lesion of orange stem near base of the leaf petiole before the tissue had collapsed. The Citrus blast bacteria were found most abundant in the phloem region (C) of the inner bark in about the same zone as the bast cells. A, epidermis; B, cortex with oil vesicles within it; C, phloem containing the sieve tubes, with clusters of larger thick walled cells, the bast fibers; D, cambium region; E, wood with radiating medullary rays; F, pith. Enlarged about 10 to 15 diameters.

painting on a suspension of the organism. The leaves which were rubbed without painting with this organism simply took on a grayish discoloration without any reddish-brown color. The black-pit form of citro-necrosis is described on page 443 and illustrated in Figs. 158, 160–162.

The Causal Agent.—The causal agent in Citrus blast is a bacterial organism known as *Bacterium citriputeale*[1] C. O. Smith (1913), identical with *Bacterium citrarefaciens*, Lee (1917).

The following description is a composite from both Smith's and Lee's descriptions with amendments and additions from later cultures and tests made by Fawcett and Camp:

Bacterial cells cylindrical with rounded ends, 1.2 to 4 by 0.4 to 1.0μ (commonly 1.8 by 0.6μ), motile with one to many polar flagella, no spores or capules present; growth on standard nutrient agar pearl gray or grayish white, thin and spreading, on sterilized orange and lemon rind, straw color becoming dark fawn. Colonies circular with indistinct entire margins: liquefaction of gelatine, at first crateriform soon becoming stratiform; growth in litmus milk distinctly alkaline without separation of casein; growth in closed arm of fermentation tubes of dextrose and saccharose but no growth in tubes of lactose or maltose; no reduction of nitrates; indol formation positive. Upper limit of H-ion concentration in nutrient standard bouillon about $P_H5.2$.

Contributing Conditions for Blast.—The occurrence of this disease depends on a special set of factors or conditions, the ranges for some of which appear to be rather narrow. Some of the principal factors which contribute to the occurrence of the disease are moisture, temperature, injuries, susceptibility of species or varieties, types of growths, etc.

Moisture.—Observations have indicated that the severity of Citrus-blast injury is dependent upon the moisture during the early part of each year under northern California conditions, usually from January to March. The disease was quite severe during some years and mild or of small importance in other years. It also seemed evident from observation that when the leaves were covered almost continuously for several days with a film of water during cool rains, the disease developed rapidly, while its development was slower when the weather was such as to allow the foliage to become dry. In accordance with Hodgson's observations from 1912 to 1918, and ours from between 1919 to 1922, these eleven years have been divided into two groups, one in which the blast was said to be severe and the other in which it was considered at Oroville, Cal., to be mild. The following data shows the rainfall, number of days of rain and of totally cloudy days for the period between Jan. 1 and Mar. 31 for each of these years (Fawcett Horne and Camp, 1923).

---

[1] According to the new nomenclature adopted by the Association of American Bacteriologists, the name would be *Phytomonas citriputeale.*

TABLE 3.—RAINFALL, NUMBER OF RAINY AND CLOUDY DAYS FOR JANUARY, FEBRUARY AND MARCH, AT OROVILLE, CAL., IN RELATION TO CITRUS BLAST

	Rainfall, inches	Days of rain	Cloudy days
Years in which Citrus blast was severe:			
1915	23.52	36	60
1916	20.28	44	55
1919	14.28	37	51
1921	11.15	30	29
1922	12.77	37	35
Averages	17.40	37	46
Years in which Citrus blast was mild:			
1912	6.26	23	48
1913	9.16	20	27
1914	15.80	24	39
1917	10.01	19	27
1918	12.93	26	49
1920	7.26	23	38
Averages	10.24	22	38

TABLE 4.—RAINFALL, NUMBER OF RAINY AND CLOUDY DAYS FOR JANUARY, FEBRUARY AND MARCH, AT RIVERSIDE, CAL., WHERE LITTLE OR NO CITRUS BLAST OCCURS

Years	Rainfall, inches	Days of rain	Cloudy days
1915	8.6	21	18
1916	12.47	28	10
1919	4.60	18	13
1921	5.03	16	14
1922	8.58	22	14
Averages	7.85	21	14
1912	0.75	15	12
1913	4.19	5	4
1914	10.01	20	20
1917	4.25	17	13
1918	8.32	18	12
1920	7.74	23	21
Averages	5.87	16	13

It is seen that the records for the number of rainy days in the severe group of years at Oroville, Cal., are higher than those in the mild group of years. This feature of the weather is probably the most important in its influence on Citrus blast. The number of totally cloudy days, in general, was higher in the severe years than in the mild years and this is also true of the rainfall. In 1921, one of the severe years, when the rainfall was comparatively light while the number of rainy days was fairly large, the blast appeared early because of heavy December rains which are not included in this record. In 1914, one of the mild years, the rainfall for the period was fairly heavy, but the number of rainy days remained few and was small in February and March. A study of the weather data for the same period at Riverside shows that in only one year, 1916, of the eleven recorded did the number of rainy days approach even the lowest figure for the severe years at Oroville, and in most years it was below the average for the mild years at Oroville. The highest number of cloudy days at Riverside for the period covering the eleven years was considerably below the lowest at Oroville. This is probably one of the main factors in the situation; at least it may account for the extremely slight occurrence of Citrus blast in sections like Riverside, Cal.

That the number of rainy days may be an important factor is further borne out by the fact that in 1922 Citrus blast occurred to a considerable degree in an orchard on the foothills below Mt. Wilson near Pasadena, Cal., where the rainfall from January to May was about 30 inches, accompanied by much fog, severe winds and cool weather resembling that of normal years at Oroville, Cal. The strong winds producing the necessary injuries near Pasadena were from the northeast, and it was also on the northeast side that the majority of the Citrus blast lesions were found.

Hail is a special form of moisture that may contribute to the severity of blast. Hail injuries on the leaves, twigs and fruit are ideal places for the blast organism to enter and produce lesions. A number of such cases have been observed. Rain and moist weather are likely to follow hail. Rain accompanying wind is also an important contributing factor. The wind whips the branches, causing breaks in the wings of the petioles or other susceptible places and the rain keeps all the surface injuries moist and probably helps to scatter the organism from place to place. This so-called "driving rain" is probably one of the most important factors in dissemination. After a few days of such rains, it is possible to isolate the causal organism from drippings from any of the leaves of infected trees, whether they be healthy or diseased.

Relation to Injuries.—After a careful study of the development of the lesions and of inoculation tests, it has been determined that infection leading to development of blast or black pit usually takes place in slight rifts, tears, scratches, thorn pricks, scars, rubbings or other injuries and does so most readily if these injuries are fresh and kept moist by rains or fogs. In counting the kinds of injuries and lesions resulting therefrom on 1138 leaves from a representative tree in which Citrus blast was active, the following data were obtained:

TABLE 5.—SHOWING RELATION OF INJURIES TO DEVELOPMENT OF CITRUS BLAST

	Breaks in one wing of petiole	Other injuries	No apparent injury	Total
Number of leaves counted	384	242	612	1138
Leaves not infected	52	184	505	741
Leaves infected	332	58	7	397
Per cent infected	86	24	0.9	26

It is here seen that the main portion of the Citrus-blast lesions developed from a certain type of injury in the wing of the petiole such as is shown in Fig. 92. The disease may also develop in other punctured or torn places in the leaf blade, in rubbed places and in injuries made previously by Fuller's rose beetle. In this last case, however, the proportion of lesions to the whole number of such injuries was rather small, probably because they were made before the active period of the blast began. A few lesions were found where no apparent injury could be detected with a hand lens, although it was not ascertained with absolute certainty that none of the cells had been previously injured.

In contrast to these records, which were taken from trees exposed to the wind, a total of 712 leaves was counted on similar growth on the south side of trees protected from south wind by large olive trees. Of these, only thirty-four, or about 8 per cent, were injured. Lesions had developed in thirty-one instances, or 23 per cent, of these injuries and mostly in breaks in the wing of the petiole.

Temperature.—Temperature, especially within certain limits, also has an important influence on the development of Citrus blast. In an orchard under natural conditions, it is especially difficult to estimate the influence of temperature apart from humidity, since the latter usually varies with the former. The temperature, of course, influences the host as well as the parasite, which makes an analysis of the temperature influence difficult.

In an orchard where blast was developing actively in 1921, temperature records showed the following average daily maximum and minimum temperatures for January, February and twenty-four days in March. The humidity record, which was kept during February, showed an average maximum relative humidity of 96 and an average minimum of 53 per cent.

TABLE. 6.—SHOWING TEMPERATUES DURING SEASON FAVORABLE TO CITRUS BLAST

	Maximum, degrees Fahrenheit	Minimum, degrees Fahrenheit
January	50	37
February	64	45
March 1 to 24	77	52

It has been observed in Butte County, California, that in the spring soon after the weather becomes warmer and drier the active development of lesions no longer takes place. It is possible that a change in the host may also be a factor in this instance, as it is in so many plant diseases; but temperature as well as moisture is an important factor in infection and development of blast, as has been shown by inoculation experiments under controlled conditions by Fawcett, Horne and Camp (1923).

There is also a suggestion that chilling followed by higher temperatures may render the tissues more susceptible to the invasion of the organism. This is in keeping with the observation that Citrus blast is severe after periods of low temperatures not sufficient to freeze the tissue.

Inoculations made by injecting bacteria with a hypodermic needle into the leaves of sour-orange one-year-old seedlings, growing in pots, were made at different temperatures on May 9, 1922. The trees had just begun new growth, but the injections were made in the older leaves. One plant with three leaves injected was placed at each of the following temperatures and given artificial light for nine hours each day: 47, 54.5, 62.6, 69, 77, 83.4 and 92.5°F. (8, 12.5, 17, 21, 24, 28.5 and 33°C.). Checks were injected with distilled water and kept at 8 and 21°C., but produced no spots. Dead spots were produced by the inoculations at all these temperatures. There was no enlargement after the second day in the case of leaves at 91.5°F. (33°C.), and none after the third day in the case of those at 83.4, 75.2 or 70°F. (28, 24 or 21°C.). The lesions on those at 62.6, 54.5 and 46.6°F. (17, 12.5 and 8°C.) continued to increase in size up to the eighth day, when the plants were taken out and all placed at a temperature of 64.5 to 68°F. (18 to 20°C.). In the next six days, the lesions on the one which had been at 54.5°F. (12.5°C.) increased rapidly and caused more injury than any of the others. Those on the one which had been at 62.6 and 46.6°F. (17 and 8°C.) also increased somewhat. Those on the one which had been at 70°F. (21°C.) or above failed to increase after removal from the chambers, and the lesions appeared the same size as they were at the end of the third day. The spots on the leaves at the higher temperatures varied from dark to reddish brown, and those on the leaves at the lower temperatures from dark brown to black in color.

These experiments, together with many others not recorded, indicate that temperatures of about 68°F. (20°C.) or below are most conducive to the development of Citrus-blast lesions, and that lesions may develop well at a constant temperature of 54.5°F. (12.5°C.) and may develop slowly at temperatures as low as 47.3°F. (8.5°C.). (Fawcett, Horne and Camp 1923).

Type of Growth.—Some types of growth appear to be more apt to be severely affected by blast than others. For example, a long succulent shoot of navel orange, grown in the late summer or fall, is especially liable. Under northern California conditions, such shoots are often angular and tend to have thick, rather brittle leaves with fairly large wings on the petioles. When the winds with rain appear, these long shoots are whipped about, with the occurrence of many slight tears or breaks in the leaf petiole (Fig. 92).

Susceptibility of Species and Varieties.—Differences in susceptibility of varieties to inoculation do not appear to be so striking as in certain other diseases. Observations in localities where Citrus blast is prevalent indicate that all the varieties commercially grown in California are more or less subject to it. It has been seen on sweet orange (*Citrus sinensis*), sour orange (*C. aurantium*), grapefruit (*C. maxima*), Satsuma orange (*C. nobilis* var. *unshiu*), tangerine (*C. nobilis* var *deliciosa*), lemon (*C. limonia*), lime (*C. aurantifolia*) and citron (*C. medica*). Hypodermic injections of the leaves of sweet orange, sour orange and tangerine appeared to give about equal results. The same injection into lemon leaves produced less effect than on the other three species, indicating a greater degree of resistance. This is also in agreement with observations in the orchards where lemon lesions when formed on the leaves and twigs are fewer and smaller than on the sweet orange. This difference in susceptibility, however, may not be true under all conditions, since lemon trees in Italy, according to Savastano (1923), are the most susceptible to blast (mal secco), the susceptibility passing from lemon in a descending scale through sweet orange, tangerine and sour orange. The differences just noted in regard to blast lesions on leaves and twigs of sweet orange and Eureka lemon under California conditions are reversed with respect to black-pit lesions of the fruit due to the same organism; *e.g.*, sweet-orange leaves and twigs are more susceptible than lemon leaves and twigs, sweet-orange fruit is less susceptible than lemon fruits (p. 446).

Control.—The results obtained with other bacterial diseases of plants, such as pear blight and walnut blight, for example, would not lead one to suspect much relief from spraying. Pear and walnut-blight organisms, however, attack the young immature tissue, while the Citrus-blast organism invades the mature tissue before any new growth starts in the spring. For this reason, one might theoretically hope more easily to cover the twigs so completely with a bactericide that infection from blast would be prevented.

Preventive Experiments.—Spraying experiments, carried on for three consecutive years near Oroville, Cal. (Fawcett, Horne and Camp 1923) and followed by experiments for two more years with the assistance of the

Extension Division, University of California, have shown that if Bordeaux mixture is applied as early as Nov. 1 (five to nine weeks before the first visible appearance of the blast), a considerable percentage of the disease may be prevented. In various experiments, the number of lesions were cut down to one-half to one-fourth the number occurring on unsprayed trees by the application of 5-5-50 Bordeaux mixture about Nov. 1. Spraying later than this had no practical effect. Ammoniacal copper carbonate had an appreciable effect, though not so much as Bordeaux, but lime sulfur (1 to 30) had no measurable effect whatsoever in the prevention of blast. Mercuric cyanide (1 to 500) had preventive effect in some cases, but in others proved injurious to the fruit and leaves without proving of much value in prevention. In the experiments with Bordeaux spraying in 1922, it was found by careful counting of lesions that the preventive value was relatively less effective on the windward side than on the side away from the wind. It is believed that the driving rains with the wind (from the south at Oroville) had a tendency to lessen the relative efficiency on the south as compared to the north side. Although it has been shown that thorough spraying experimentally with Bordeaux mixture will prevent a considerable amount of blast infection, it has not yet been definitely proved that this practice is commercially profitable.

Suggestions for Prevention.—These suggestions should be considered as applicable only for localities similar to Butte County, California, where climatic conditions are such as to make blast severe. In sections like southern California, where blast is only a minor disease and is rarely seen on leaves and twigs, it is not sufficiently important to demand a remedy.

1. Methods of fertilizing, irrigation and culture that will insure a good healthy growth of shoots and leaves before fall sets in are desirable. An untimely growth in autumn, that does not have sufficient time to harden before cold weather or that consists of long succulent shoots too late in the season, has been observed to be especially susceptible to blast. Such growth is not only more subject to injury by driving winds with rain, but is thought to be inherently more susceptible to infection.

2. When possible, it is advisable to provide some means of protection against winds. Such protection in itself has been observed to prevent a large part of the blast by preventing injuries to the petiole of the leaf. In new plantings, windbreaks might be provided by means of suitable trees planted close together in rows at right angles to the prevailing moist winds. In some cases, this might be arranged by planting alternate or frequent rows of other profitable fruit trees of a type that would serve also as a windbreak for the Citrus.

3. For new plantings, a variety or type of tree, having a bushy, compact form of growth free from thorns and, therefore, a minimum liability to injury during severe wind storms, should be considered. Some of the Satsuma-orange varieties have been observed to be less liable

to blast, probably because of their more compact, less easily injured type of vegetative growth. Their growth may also have slightly more inherent resistance to the disease.

4. In cases of very severe blast on young trees the following suggestions are made: Prune out as many of the dead, badly diseased twigs of the previous year as possible and spray about Nov. 1 (in northern California), or five to nine weeks before the active period of blast, with Bordeaux mixture 5-5-50 (with the addition of 1 pound of a spreader, such as casein). Special care in spraying should be used to cover all the new growth that has been made during the previous year.

If blast should ever become important in localities where beneficial scale fungi are present, the Bordeaux-oil emulsion should be used. Spraying trees with Bordeaux mixture would be detrimental in places where fumigation with cyanide is regularly practiced. It is as yet uncertain, however, whether spraying is economically profitable for large bearing trees even under northern California conditions.

RUBELLOSIS OR PINK DISEASE

Rubellosis or pink disease derives its name from the color of the causal fungus, which is very conspicuous and a rather distinctive salmon-pink color. It occurs not only upon Citrus species but upon many species and genera of widely separated families of plants. The chief economic hosts are Citrus species, the commercially grown rubber (*Hevea brasiliensis*) the cacao (*Theobroma cacao*), coffee (Coffea species) and tea (Thea species). In tropical countries, it is one of the most destructive diseases of Citrus species and apparently is widespread in such tropical countries.

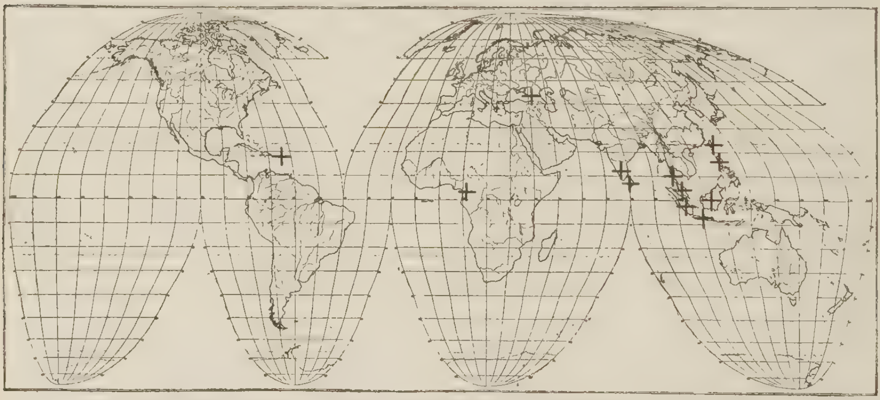

FIG. 94.—Map showing known distribution of rubellosis or pink disease.

History and Distribution.—Pink disease first attracted attention on coffee in 1897 in Malaya. It has since been reported on various hosts from Java, Sumatra, Borneo, Ceylon, India, Formosa, the Philippines, the Caucasus, the Cameroons, Porto Rico and Dominica. It is appar-

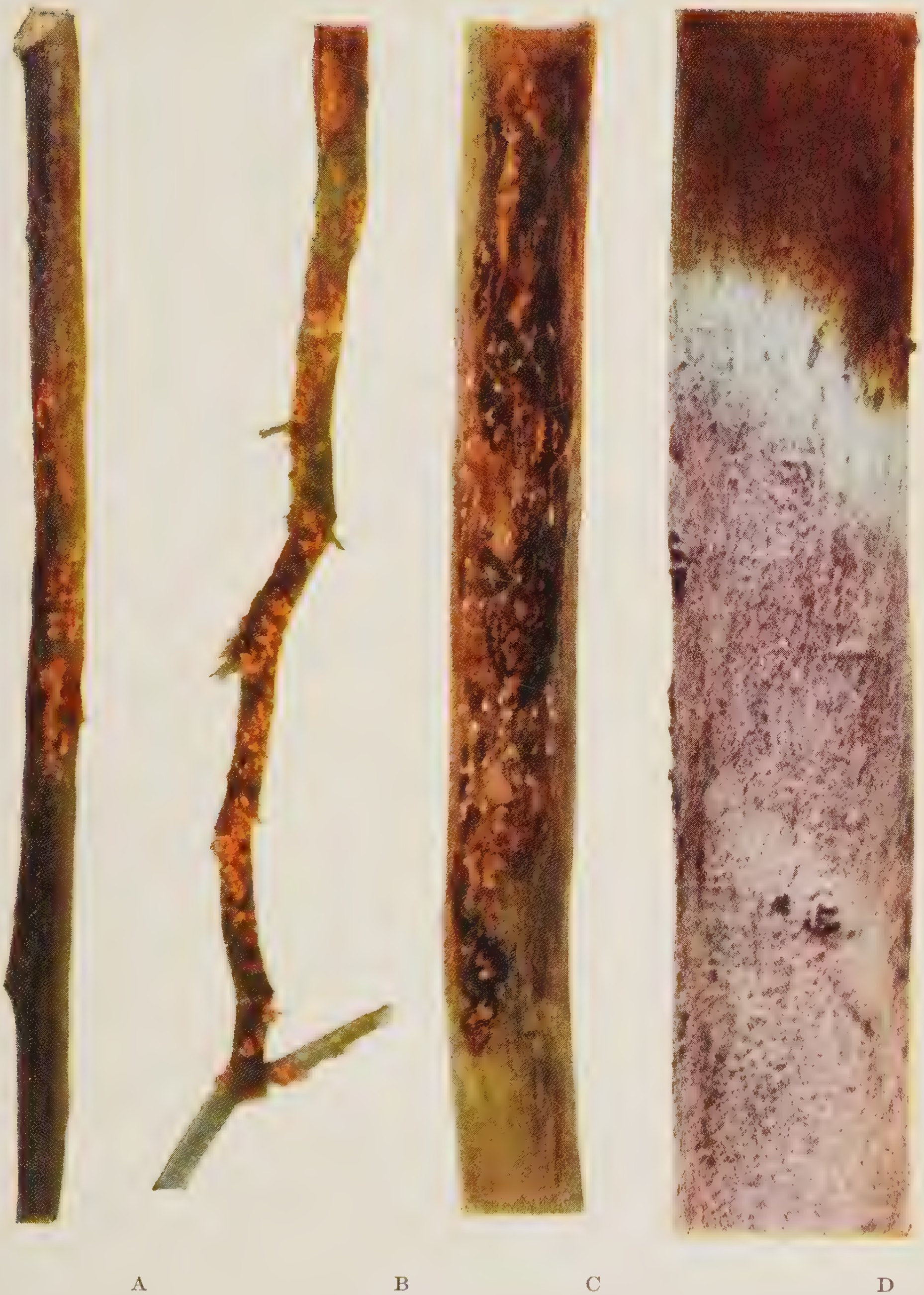

FIG. 95.—Rubellosis or pink disease due to *Corticium salmonicolor.* A, Branch showing the salmon-pink color of the Corticium stage of the fungus with white advancing mycelium. B, Early stage with gum formation and sterile pustules within the bark. C and D, Necator stage of the fungus with orange-colored pustules (sporodochia) containing spores.

(*Facing page* 304)

ently of widespread occurrence in the tropics of the eastern hemisphere but is not so widely known in the western tropics. In countries of the temperate regions, it has not been very generally reported (Fig. 94).

Symptoms on Citrus Hosts.—The first stage of the disease appears to be a slight gumming, similar in many ways to the gumming which is produced coincident with many other injuries to the bark of Citrus. At this stage, the bark seems dry and very hard, adhering closely to the wood. Often longitudinal cracks form in the bark at the same time with the gumming.

Usually, the first appearance of the fungus is in the form of pustules, which push through the hardened bark. These pustules are dirty white to pinkish in color, usually 1 millimeter or less in diameter and rather irregular in shape when observed under the hand lens; so far as known, they are sterile (Fig. 95). Following the sterile pustule stage, or sometimes occurring without any appearance of it, there is a formation of the mycelium of the fungus over the surface of the branch. This mycelium spreads and extends over the entire lesion, forming a pink incrustation which varies somewhat in shade but perhaps typically approaches most closely orange pink. This color is the most striking characteristic of the fungus, as shown in Fig. 95. The incrustation is at first almost entirely smooth and of a velvety appearance, but with age it becomes roughened and broken up into patches, passing through transitional stages of color until it finally fades out to a dirty white. The mycelium advances up and down the branch as a characteristically delicate, smooth, fan-shaped, white mycelium.

In some cases, upon cutting through the bark beneath the actively advancing mycelium, no visible effect of the fungus is found, even though the mycelium on the surface has advanced considerably beyond the cut; in others, the bark is shown to have a watery, darkened, greenish appearance; while in still other cases, the affected area extends beyond the limits of the surface mycelium. This variation may perhaps be explained by different seasonal conditions. As the disease advances, the watery appearance of the bark disappears, and the tissue becomes still darker in color and presents a dried-out appearance. The bark, at this stage, is a dry mass of shredded fibers, running longitudinally with the branch.

On Citrus, the outermost layers of the wood become discolored to a light brown. The extent of this brown tissue, however, is usually small in comparison with the area covered by the surface mycelium of the fungus. In some cases, the discoloration of tissue has been observed to extend deep into the wood. Brooks and Sharples (1914), in their study of the disease on rubber, found that the fungus hyphæ followed the medullary rays well into the tissue.

The final effect of the growth of the fungus is the stoppage of the water conduction, followed by the wilting of the leaves and the ultimate death of the affected limb. This last stage takes place very rapidly; frequently the leaves wilt, become yellow and drop within five days. Small twigs, main branches or even trunks of trees are attacked. The fungus has never been observed on roots. Pink disease when uncontrolled causes serious injuries and often results in the death of entire trees by girdling the trunk. It is a killing disease rather than one that merely lessens the financial returns by lowering the efficiency of the tree.

Pink disease or rubellosis has been found upon practically all the species of Citrus and several related genera of the Rutaceæ. Apparently, all species and varieties of Citrus are susceptible.

The Causal Agent.—The causal fungus, *Corticium salmonicolor*, was first described by Berkeley and Broome (1873). Without knowledge of this first description, the fungus was also described in 1901 from Java by Zimmerman (1901) as *C. javanicum*, but it was subsequently shown by Petch (1911) to be identical to *C. salmonicolor*. Another synonym is the *C. zimmermanni* of Saccardo and Sydow.

There are three stages: a resupinate, typical Corticium stage; a sterile pustule stage called by Dutch botanists the "Höckerchen" form; and an imperfect form known as the Necator stage. The Corticium stage is most frequently observed; the hymenophore is resupinate, membranous, smooth in small areas with frequent erumpent warts, white at margin but typically salmon-pink color over most of its area. The typical appearance and color are shown in Fig. 95. On Citrus, basidia and basidiospores were not observed, but they have been observed on rubber and are mentioned and shown in illustrations by Brooks and Sharples and reproduced here in Fig. 96.

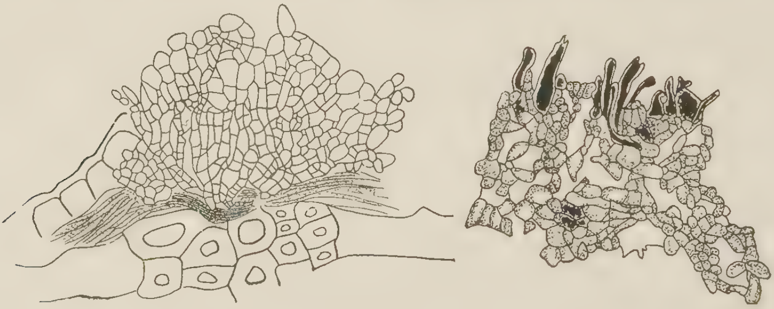

Fig. 96.—*Left*, a fully developed pustule of the Necator stage showing the thin-walled irregular-shaped spores. *Right*, a section of the pink hymenophore showing basidia and sterigmata. (*After Brooks and Sharples* (1914).)

The sterile pustule form usually shows before the Corticium stage in the form of small sterile pustules, from white to salmon pink in color, also shown in Fig. 95.

The imperfect stage was first described as a distinct species, *Necator decretus*, by Massee (1898), but inoculation experiments by Rant (1912) showed the identity of this form with *C. salmonicolor* of Massee. Small erumpent bodies known as sporodochia arise from the bark, usually preceding or independent of the Corticium stage. They are scattered, sessile, slightly convex and characterized by a distinctive orange-red color, quite different from the salmon-pink color of the Corticium stage. The conidia are oblong to irregular in shape, thin walled, catenulate and hyaline. This stage is also shown in Figs. 95, 96. A very complete description of the fungus is given by Brooks and Sharples (1914). The Necator form with its abundant formation of spores would seem to be the most important stage for the dissemination of the fungus.

Contributing Conditions.—Although the temperature and moisture relations of the fungus are not known, the recorded occurrence of this disease indicates that it is primarily a disease of tropical countries in which long periods of warm wet weather occur. It is probably not a disease which would be serious in Citrus-growing countries of temperate regions such as California, Florida or Japan. The appearance of all stages of the fungus is, moreover, much more common in the seasons of rainfall, rather than the dry seasons, indicating that in relatively dry countries the disease would not be so serious. Pink disease also occurs most seriously in well-cultivated orchards rather than in trees under conditions of neglect. It seems probable that the disease is primarily one of vigorous, actively growing trees rather than those of comparatively poor growth. The susceptibility of young and old trees seems to be equally great.

Prevention.—Experiments by Lee and Yates (1919) in the Philippines showed a very effective control by pruning out affected limbs with proper disinfection methods accompanied by preventive spraying. Lime sulfur is preferred to copper sprays in such spraying work, since fungicides as Bordeaux and Burgundy mixtures control the fungi which are parasitic on Citrus-scale insects and result in a consequent damaging increase of the scale insects. When copper sprays are advisable, the addition of an oil emulsion to the spray mixture is essential to keep down the insects. The time and number of applications will, of course, depend upon the seasonal conditions of the country in which the disease occurs, but, in general, the fungus is controlled so easily by fungicides that few applications are necessary. They should be made, of course, in the rainy season when the conditions are most favorable for the dissemination of the fungus. In the Philippines, where there is a rainy season of from four to six months, four applications following the pruning out of sources of infection resulted in a very effective control. After the orchard is well cleaned up of sources of infection, it would be expected that spray applications could probably be reduced in number and frequency. Such control measures, therefore, are inexpensive as compared with the numerous spray applications required for some diseases.

For those Citrus-producing countries in the tropics in which pink disease does not yet occur, inspection and quarantine measures, to exclude the disease entirely are obviously the cheapest prevention. Even those countries in temperate regions where pink disease does not yet occur should preferably depend upon such inspection and quarantine measures for prevention rather than on their climatic conditions, since entire exclusion would appear to be much the safer measure.

DIPLODIA TWIG BLIGHT

In certain parts of Florida and the West Indies, twigs are killed back by a fungus similar to *Diplodia natalensis.* That this fungus was active in the death of twigs on both Citrus and peach trees in Florida was first shown by inoculation experiments by Fawcett and Burger (1911*a*). Earle and Rogers (1915) showed that a similar fungus was active in connection with "twig dieback" in the Isle of Pines, Cuba. Nowell (1923) considers a similar Diplodia to be important as a secondary agent in dying back of lime twigs in the Lesser Antilles. The same fungus also attacks the bark and wood of larger limbs and trunk and the fruit (see discussions on pp. 190 and 409).

Symptoms.—This Diplodia twig disease is likely to be confused with anthracnose or withertip, which it sometimes resembles. In fact, the anthracnose fungus, *Colletotrichum glœosporioides* Penz. and *D. natalensis,* are often associated and probably do more injury in combination than when each is working alone (p. 37). Diplodia twig blight may take several forms:

1. The twigs may die back from the tips for some distance ending at a "sharply defined line which separates the diseased from the healthy tissue." The self-limiting is usually accompanied by more or less evident gumming, and it would appear, as Earle and Rogers (1915) have pointed out, that the gum serves to stop the further invasion of the organism. Sometimes, no limiting line develops until the entire twig and part of a larger branch or trunk below is involved and girdled. In moist climates, the bark that has died is eventually dotted by minute black pustules, the pycnidia of the Diplodia fungus. Sometimes, a reddish-brown color of the dead bark on larger limbs gives an indication that Diplodia may be present. (Fawcett 1912*c*, 1913*a*).

2. The Diplodia attack, at other times, may not begin at the tip but at a point farther down. It may then girdle the branch or twig and cause the foliage beyond to wither and dry up suddenly.

3. A special discussion is necessary in connection with the effect of Diplodia dieback on lime trees in the West Indies. Nowell (1923) points out that the growing leaders on the lime trees, which are at first upright, soon become inclined. New vertical shoots grow up from the curved upper portions of the old. These in turn bend over and the process is repeated many times over, until a tree which has space for full development becomes dome shaped with a continual tendency to the opening up of the center. If the water supply does not suffice for both young and older branches, the ends of the outer, bent-over branches stop growing and die back, the newer, more upright shoots remaining alive. The new growth may for a time balance these losses, but may later fall behind. Heavy crops and dry seasons accelerate this declining condition. This

dying back is closely accompanied by Diplodia infestation, and when branches of some size begin to die back the disease tends to progress rapidly, with formation of long lesions and a considerable flow of gum. As in the case of other Citrus varieties, a self-limiting demarcation usually takes place at the base of smaller branches.

A dying back of roots in much the same manner as that in the twigs and branches is mentioned by Nowell (1923) as occurring on lime trees in Montserrat. This is accompanied by Diplodia and other fungi. As far as known, the exact relation of the fungus to death of the roots has not yet been shown by inoculation experiments. The injury according to Nowell is often complicated by long groove-like wounds, made by larvæ of the genera Diaprepes and Exophthalmus, into which weakly parasitic fungi may enter and progress in trees of low vigor.

Contributing Conditions.—Maturity of tissue while still weak, wounds and deficient or unfavorable nutritional conditions are contributing factors. The sudden stoppage of growth with the setting in of drought heavy fruiting and poorly nourished trees on light sandy soils are mentioned by Earle and Rogers (1915) as supplying favorable conditions for attack. Of the grapefruit varieties, the Triumph is especially susceptible. With the lime tree, Nowell finds that the locations in the West Indies having most Diplodia twig dying have reduced rainfall, lower humidity, more exposure to wind and a more marked difference between wet and dry seasons than those locations having less of the disease.

Control.—Where Diplodia twig disease is due to any of the unfavorable conditions, such as insufficient amounts or kinds of fertilizing or other deficiency that is within the grower's control, something may be done to prevent its attack by remedying the deficiency. In other cases where there is seasonal occurrence of unfavorable environmental conditions, outside the grower's control, considerable resistance can probably be built up by keeping the trees in a vigorous condition at all times.

In discussing preventive measures for Diplodia dieback of limes in the Lesser Antilles, Nowell (1923) states that the underlying cause

> . . . appears to be one of insufficiency and irregularity of water supply, and the duration and completeness of the dry season seem to have more effect than the intensity of the wet.

In view of this principle, close shelter to preserve moisture, and windbreaks in all exposed positions are recommended. Constantly maintained surface mulches are also suggested as a possible advantage. Laying stress on the predisposing conditions for "Diplodia dieback," it is pointed out that "where the disease begins opposite the same gap which lets in the wind," the decrease in foliage on the first trees gradually exposes the trees behind them to the same conditions, as a result of which the disease may seem to spread as though it were infectious.

Treatment.—When the disease has begun to travel back to the larger limbs, the branches should be cut back well into the healthy wood and flush with a side branch. If the climate is a moist one, the cuts may be treated with a good disinfectant or fungicide (Chap. VI). After drying for two to six days according to the weather, they may then be covered with white-lead paint, asphalt paint or other good covering. In dry climates in summer, it may be safe to use asphalt paint or other safe coal-tar products, soon after cutting, without first disinfecting the wounds.

SCLEROTINIA TWIG BLIGHT

Dying back of twigs from the attack of the fungus *Sclerotinia libertiana* occurs under certain conditions in the orchard and in the nursery. It is usually a minor disease in California, but at times may become serious on individual trees. It is most apt to follow periods of moist cool weather in which there has been frost or at least temperatures close to those of frost injury. The Sclerotinia fungus grows well in low temperatures. Its relation to twig blight has been carefully studied under California conditions by C. O. Smith (1916*a*). The same fungus is involved in Sclerotinia rot of roots (p. 103), Sclerotinia gummosis of the trunk and larger branches (p. 153) and cottony rot of fruit (p. 380).

Symptoms.—The disease may start either at the end of the twig or in the blossoms and spread back for short distances, or it may start farther back on a twig or limb, girdle it and cause the distal portion to wither up suddenly. It may start in slight injuries or in dead moist tissues, from which it spreads rapidly for a short time into sound tissue. On lemon trees, it may attack clusters of blossoms, presumably beginning in the decadent petals, from which it spreads into the twigs. The bark tissues are at first soft, and a considerable amount of gum exudes. The invaded bark later dries down and assumes a light color indicated by Ridgway's (1912) chart by shades of light buff to warm buff. It also assumes a shredded, fibrous condition on larger twigs on weathering. This fibrous, shredded condition is fairly characteristic of Sclerotinia attack, although the pink disease in the Orient produces a similar effect. A related fungus, *Botrytis cinerea,* may soften the bark in the same manner as Sclerotinia, but the bleached, whitened appearance followed by the shredded, fibrous condition is not so likely to result. Black, flattened sclerotia in and under the bark sometimes develop on twigs, but not so frequently as on large branches or on the thicker bark of the trunk or large roots (Fig. 10). The fungus usually girdles the twig, but if the weather or growth conditions become unfavorable for the parasite, a small side lesion may result without girdling the twig. The advance of the fungus along the twig is soon arrested, and this halt is usually coincident with considerable gum flow at the margin of the lesion.

Contributing Conditions.—Some of the contributing conditions for Sclerotinia twig blight, such as frost with cool moist periods, have already been mentioned. Investigations and observations indicate also that dead tissue or organic matter of any sort in contact with the tissues is an important condition for infection. The spores germinate and grow for a short time in such a medium and from this readily enter and destroy sound tissue. The fungus does not seem to be capable of readily entering sound tissues at once, but must use this indirect method of invasion. Infected decadent petals, decayed fruit that has lodged in forks of the branches and a bit of dead functionless bark are suitable media from which the fungus may indirectly invade sound tissues.

The same fungus may attack a large number of other hosts. It sometimes happens that the winter cover crop of legumes between the rows are attacked, increasing the growth of the fungus. The dark, seed-like bodies or sclerotia are produced, which live through the dry season and give rise to the spore stage the following year (Fig. 126).

Control.—Sclerotinia twig blight is usually of such minor importance that no systematic control measures are necessary under California conditions. The diseased twigs, however, should be cut out and destroyed to prevent them from being possible sources of infection. The disease has rarely been seen in clean cultivated orchards free from bulky organic matter or winter cover crop. Many growers, however, would prefer a slight injury from Sclerotinia rather than forego the advantage to the trees of sufficient organic matter and cover crops in the orchard.

BOTRYTIS TWIG BLIGHT

The fungus, *Botrytis cineria* Lk., frequently attacks twigs in much the same way and under the same conditions as the foregoing fungus, *Sclerotinia libertiana*, to which it is related. In the early stages, the effects of the two fungi on twigs can scarcely be distinguished.

Distribution.—This form of twig injury is found occasionally in California. Species of Botrytis have been reported frequently on twigs and fruit in southern Europe. In Victoria, Australia, Brittlebank (1915) reported a Botrytis disease on twigs and on young trees which were apparently killed by it. He reports that the first record of it in Australia was in 1900 and that it again occurred in 1911 to 1913. In a letter received in 1924, he reports it to be a serious disease on young lemon and orange wood. It appears as a "yellowish-buff spot" and spreads rapidly, encircling the limbs, but rarely produces the fruiting stage on the killed parts. Twigs or branches 1 inch in diameter or smaller are attacked. It has been found seldom on larger limbs. K. M. Curtis reports it to be present in New Zealand in neglected trees in private gardens and as a blossom infection.

Symptoms.—The bark tissues are softened, as in Sclerotinia twig blight, and after the fungus has invaded the bark for some distance, gum exudes coincident with the checking of its spread in the bark. Botrytis usually does not spread so rapidly nor so far along the twigs as does the Sclerotinia. The main difference in its appearance is the formation of gray fruiting bodies in cool moist atmosphere on the softened bark in a continuous mass suggesting the fur of a gray mouse. In a dry atmosphere, these are usually absent. The dark sclerotial bodies are rarely present, or, if present, are smaller and the bark not so light in color nor so completely shredded and fibrous as in Sclerotinia twig blight.

The contributing conditions and control are the same as for Sclerotinia twig blight. Other effects of *Botrytis cinerea* are Botrytis gummosis (p. 183) and Botrytis rot (p. 385).

CITRUS BLIGHT

Blight in Citrus is a malady of unknown cause which appears to be confined in most part to certain sections of Florida. It has been reported doubtfully also in Cuba and Porto Rico. It is a disease manifesting itself in a slow general deterioration of the whole tree, but because the first symptoms are seen in the leaves, it is included in this section.

History.—So far as known, this disease has not been identified certainly outside of Florida. The disease was carefully described and illustrated by Swingle and Webber (1896), who state that it had been known for about twenty to twenty-five years previous to 1896. A reliable previous account of the disease had been published by Underwood (1891). A discussion of the disease is reported in the Florida State Horticultural Society Proceedings for 1892, and for a number of years blight was one of the most dreaded diseases of Citrus in Florida. In later years, the disease has not spread generally nor alarmingly over the entire state but appears to be confined principally to a few sections where, however, it has by no means died out but continues to injure Citrus trees, a few being killed out each year (Burger, 1923*a*). A large amount of scientific study and investigation has been done upon blight without so far finding anything that could satisfactorily explain the cause of the trouble.

Symptoms.—The identification of this disease by one who has not had experience with it is difficult, since other effects are easily confused with it. The first symptom of blight is usually a wilting of the foliage on trees of considerable size and age, suggesting that the tree is suffering from lack of water (Fig. 97*B*). Usually this occurs in early spring in Florida and at first appears most pronounced on dry hot days, but later this wilting continues through damp, wet weather. Most frequently, a single limb near the top will show signs of wilting, after which this condition will spread to the other branches. As the disease progresses, the

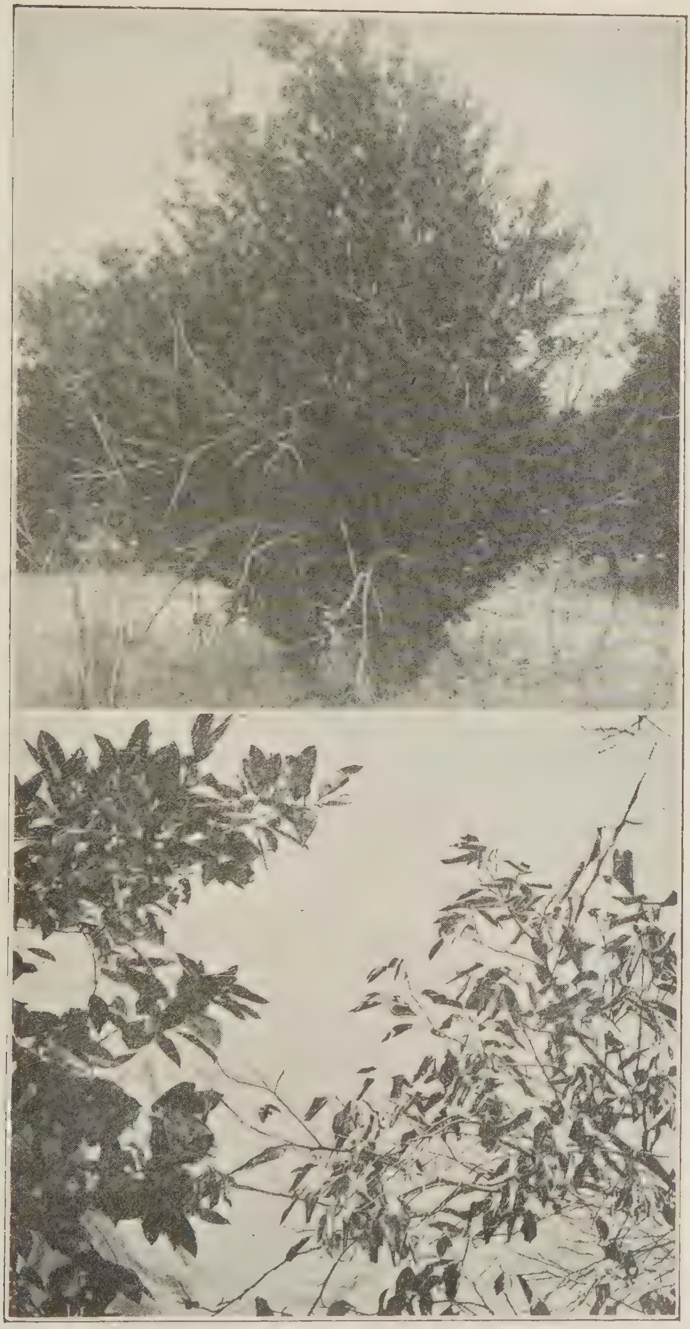

FIG. 97.—*Upper*, dead branches and sprouts from the base of orange tree as the result of Citrus blight in Florida. (*Fla. Exp. Sta.*) *Lower*, Citrus blight foliage on the right contrasted with normal foliage on the left. (*After Swingle and Webber* (1896).)

leaves often drop off, or in some cases the wilting may occur so suddenly that the dry leaves will remain hanging to the twigs. After the top has been injured, numerous water sprouts put out from the trunk and larger limbs (Fig. 97*A*). These appear healthy at first and seem to give promise of a new healthy tree, which only sickens and dies later. Branches that first show blight may, for a year or more, retain some foliage that is small and "dingy green" in color. After a tree is attacked by blight, it may produce profuse blossoms out of season, but very little fruit sets. According to Swingle and Webber, a majority of trees affected by blight have a healthy root system and put out new shoots from the trunks after the top has died back. These shoots remain healthy in appearance for a time, but in a year or two show the same symptoms. Since there are no striking characteristic anatomical features in any part of the tree by which blight may be identified, it is difficult to form a clear conception of the disease until one has had experience with it.

Cause Unknown.—Although a considerable amount of study and scientific investigation have been done on blight, no causal agent has been discovered. It appears to be the general belief of growers and investigators, based principally upon observation in the orchards, that the disease is transmitted from one tree to the next, but we know of no clear-cut, scientific evidence that this is the case.

Contributing Conditions.—Although blight may occur on various types of soil, it is most apt to occur on very light sandy "hammocks." Swingle and Webber state that trees growing on clayey hammock or high pine land in Florida are usually exempt from the disease.

Control.—No curative measures are yet known for blight. It is important that research be continued to determine if possible its nature and cause and whether or not the disease is transmissible.[1]

THREAD BLIGHT

The thread blight due to the fungus *Corticium* (*Pellicularia*) *koleroga* Cke v. Hohn is mentioned by Nowell (1923) as occurring on sour-orange trees in the West Indies. It is also a pest of coffee in Porto Rico, Jamaica, Trinidad, Surinam, Venezuela and Colombia.

The vegetative mycelium of this fungus occurs in the form of long slender strands nearly uniform in diameter. They are whitish at first, finally becoming dark brown. They extend along the branches, midrib and veins of the leaves and branch out between the cells of the leaf parenchyma, finally coming to the surface on the upper side of the leaf, where they form minute fruiting bodies which give a speckled appearance to the leaf. Soon, these separate spots grow together into a thin membrane of a smoke-gray color covering the entire surface of the leaf. On coffee, it reduces the foliage and often causes the death of the twigs.

---

[1] As this goes to press we have the permission of A. O. Kay, Associate Drainage Engineer, through R. W. Hodgson to state that recent investigations (unpublished) in Florida by Kay have shown that Citrus blight or "wilt" is apparently due to unfavorable moisture conditions in the soil.

Nowell reports that spraying with Bordeaux mixture, if prepared with an excess of lime, is effective in controlling the disease if followed by inspection and by an additional spraying in case of necessity. Spraying with lime sulfur is reported as ineffective.

TWIG GUMMING

A gumming and dying of a few scattered twigs, usually of minor importance, in the late summer or fall, has been observed in California and Arizona. The cause is unknown. No organism has been commonly found in the lesions. It is characterized by sudden wilting of leaves and dying back of twigs or small branches, especially of navel orange trees, to a distance of 12 to 24 inches from their tips. At the base of the dead portion, the bark splits and gum oozes out in considerable quantities. It appears to occur most often after periods of hot dry weather and has been known in California for many years as a minor trouble. It is quite distinct from Citrus blast, though sometimes confused with the latter disease. It usually occurs at a season of the year when Citrus blast is inactive and under weather conditions opposite to that favorable to Citrus-blast development. It may readily be mistaken for certain effects produced by anthracnose, and although the anthracnose fungus is frequently associated with it, the initial cause is thought to be different.

A somewhat similar gumming, associated with the dying back of twigs, and branches but without the characteristic splitting of the bark, has frequently been noted in large nursery trees. Although certain organisms have been found in the lesions, none of them have reproduced the disease on inoculation. These forms of twig gumming differ also from twig blight caused by the cottony rot fungus, *Sclerotinia libertiana*, in the absence of a whitening or shredding of the bark and in the absence of the black sclerotia frequently formed in the bark attacked by that fungus.

LIGHTNING INJURY

This injury was first called to the writer's attention while stationed at the Florida Agricultural Experiment Station. A number of growers had mistaken it at first for the possible effect of some parasitic disease. It has frequently been observed causing varying degrees of damage, usually to a few trees in an orchard, but sometimes to a large group of trees. The injury may vary all the way from sudden death of the tree to partial destruction of patches of epidermis on a few branches or twigs. The nature of the injury has been well described by Stevens (1918*a*, *c*) and by Waldron (1923), who consider it very destructive at times in central Florida. Injury from lightning has been reported on a number of other agricultural crops in the eastern states.

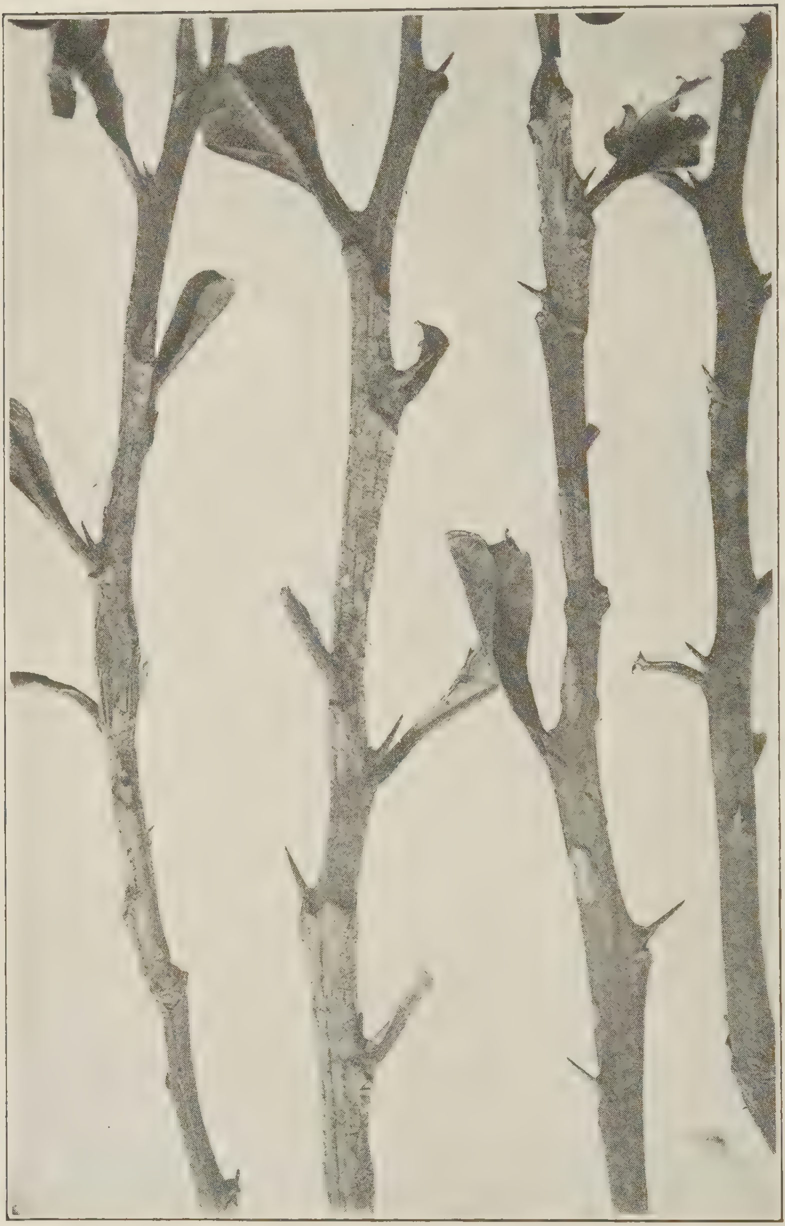

FIG. 98.—Lightning injury in Florida, showing lesions on the surface of twigs, on which the buds, thorns, and areas at base of petioles have escaped. (*After Stevens*, 1918*a*.)

Appearance of Lightning Injury.—A characteristic feature on Citrus is the formation of blotches and spots on the surface of young shoots and twigs which might easily be mistaken at first for effects of parasitic organisms. As described by Stevens, these blotches are pale greenish yellow to yellowish, varying in size and shape. These areas may cover a space 1/4 to 1/2 inch long, or they may affect the entire surface of the twig, except thorns and leaf nodes, for distances of 3 or 4 inches. The leaves, thorns and a small area surrounding the base of the petiole in most cases escape. The green leaves, thorns and areas at the leaf nodes, therefore, stand out in contrast to the discolored areas. In time, the blotches and injured areas become yellowish brown and are raised above the surrounding bark by the growth of a new bark underneath. The outer surface remains for a time smooth and glazed, but finally breaks in longitudinal slits, becomes ragged and peels off, leaving a brownish, roughened scar (Fig. 98).

In many cases, the injury appears to be confined to surface layers of the bark without preventing the renewal of the bark. When the areas have appeared, they do not enlarge beyond their original limits, unless injurious fungi, such as Diplodia, Phomopsis, Colletotrichum or other twig-inhabiting fungi, enter and advance from the injured margins. Older twigs or branches are rarely affected by these surface blotches, but in severe cases show a narrow strip of dead bark running longitudinally.

A trunk struck by lightning usually shows a strip of dead bark extending downward to the roots. At the crown, the strip sometimes broadens and girdles the trunk. The bark is killed through to the wood. The dead tissue is soon invaded by fungi and under moist conditions begins to decay rapidly. Sometimes, only a small part of the circumference of the bark at the base is killed.

Treatment.—Trees that are very severely injured and girdled should, of course, be dug out and replaced. Trees less severely injured may be treated and saved. Badly injured twigs and branches should be pruned out to the first fork or side branch back of the injured areas, since they frequently serve to multiply injurious fungi which live part of the time in dead functionless tissue. According to Waldron, if one-half or less of the circumference of the bark at the base of the trunk is killed, all dead tissue should be removed and the wound painted. Asphalt paint or other good covering may be used, or the wound may be disinfected with mercuric cyanide, mercuric chloride, carbolineum or other good disinfectant and painted afterwards (Chap. VI). If the killed area is large, inarching with small trees may be resorted to. Soil should be pulled away as far down as the injury extends and left away until callous tissue starts to form. The exposed wood should then be painted again for more permanent protection against wood rot.

ALKALI INJURY

Alkali injury is not an uncommon effect, especially in arid regions under irrigation. Since some effects of alkali on Citrus trees are frequently mistaken for definite diseases, they will be briefly discussed here. The term "alkali," as it is often used in its broad sense in connection with agricultural crops and as used here, is a high or excessive concentration of readily soluble salts in the soil or actual alkalinity in case of alkaline carbonates. Alkali injury may result either from salts occurring naturally in the soil and subsoil or from alkali salts brought to the soil by improper irrigation water or by the continuous use of an alkali salt in fertilizing.

Symptoms.—Alkali injury in Citrus has been recently studied by Kelley and Thomas (1920), who clearly describe the symptoms under California conditions. The injury varies somewhat with the kinds of salts present and environmental conditions. The most common effects are yellowing and burning of the margins and tips of leaves, the excessive shedding of leaves at certain seasons, the mottling, bronzing and curling of leaves, the production of undersized, often chlorotic, leaves, the final dying back of twigs, loss of fibrous roots and a general deterioration and lack of vigor in the entire tree.

Effect of Excessive Sodium Chloride.—The specific effect of excessive sodium chloride, or common salt, is usually shown by spots on the margins or tips of the leaf at first slightly duller in color than the normal green. The green fades out, the tissue of the spot turns a cinnamon buff to clay color and dries out. A yellow zone beyond the dead part is often formed as the spot enlarges. The effect may show first in a browning and dying back of the leaf tip with a yellowing extending back in advance of the death of the leaf tissue (Fig 99). Affected leaves often start to roll or curl. Various fungi, especially *Colletotrichum glœosporioides* and Alternaria, may develop in these dead areas and advance into the weakened tissue, especially under moist atmospheric conditions.

Effect of Excessive Sodium Nitrate.—The leaves become mottled, and if concentration becomes sufficiently high, they burn and fall off. Subsequent leaves become smaller and smaller. Repeated additions of sodium salts to certain soils may temporarily increase the supply of soluble calcium. Subsequent leaching of this dissolved calcium in the drainage water may bring about a deficiency in the soil solution. It is then that the effects of the alkali salts become most harmful.

Effect of Excessively High Concentration of Potassium.—Reed and Haas (1924) have shown that with high potassium and low calcium the leaves develop yellow spots on which brown papillæ appear. The leaves also show a condition resembling foliocellosis or mottle leaf. The roots are also injured. A burning or etching of the leaf tissue giving the impression of light sunken spots eaten out by insects has also been recently recognized by Haas as the effect of excessive potash. The tissue turns to a drab color and finally dies. Where calcium is extremely deficient along with excess of potassium, the symptoms are more pronounced and shedding of leaves occur. Where calcium is not particularly deficient but soluble potassium is excessive, the plants may still fail to absorb enough calcium due to their high absorptive capacity for potassium.

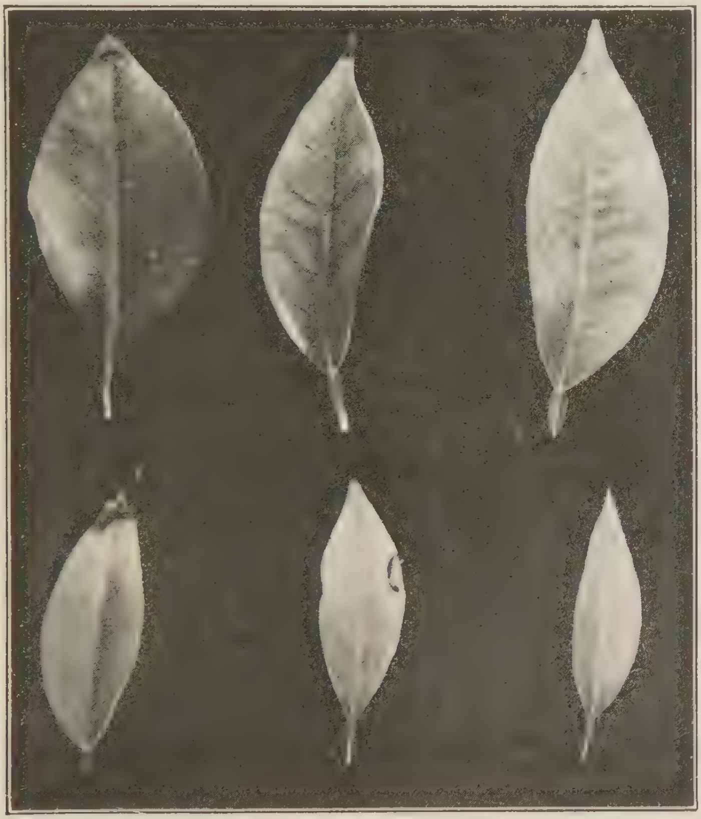

Fig. 99.—Injury from high concentration of chlorine in soil solution. (*After Reed and Haas* (1924).)

Contributing Conditions.—While alkali injury is due to the accumulation of salts in the soil and their effect on the tree, there are secondary conditions under which a given amount of salts will be most apt to produce severe injury. Adverse climatic conditions, such as very low humidity, accompanied by hot winds or high temperatures, may increase the severity of the injury. Lack of general cultural care, such as insufficient use of bulky organic fertilizers on soils low in humus, improper tillage, allowing the soil to become too dry, may all accentuate the effects. The presence or absence of certain other salts in the soil may also increase the injury.

The same amount of alkali salts in the soil injures certain varieties more than others. In general, lemon trees are more sensitive to alkali than orange trees and the Eureka variety of lemon more sensitive than the Lisbon variety. Navel oranges appear to be more sensitive than Valencia oranges.

The nature of the soil is also a contributing factor, some soils of a heavy type apparently being able to receive more alkali salts without injury to the trees growing therein than others of a lighter, sandier type. For these reasons, the definite minimum amount of a given alkali salt at which Citrus trees will show symptoms of injury cannot be stated. It varies with the other conditions.

Increase of Alkali in Citrus Orchards.—An increase of alkali from non-injurious to injurious amounts may come about in several ways, in an orchard, as Kelley and Thomas (1920) point out: (1) The alkali salts may be already more concentrated in the subsoils than in the surface soils. Under irrigation, these salts are brought up by capillarity to the root zone, or they may be brought up by temporary rise of the water table. (2) The salts may be brought to the roots by a gradual rise of water table containing high percentages of alkali salts resulting from leaching of surrounding territory. (3) The alkali may gradually accumulate from the use of irrigation water charged with alkali salts. (4) Alkali salts may accumulate as a result of the constant use of fertilizers containing alkali base-forming elements, such as sodium in nitrate of soda.

Prevention.—Alkali injury may often be prevented by avoiding the accumulation of alkali and keeping the soil in a condition to neutralize small quantities when these tend to accumulate. It is of first importance to avoid the use of irrigation water containing appreciable amounts of alkali salts in solution. It may require a number of years for sufficient amounts to accumulate to show effects in the tree. Analysis of irrigation water should be obtained before it is used in any case. If this has not been done and the least symptom of injury is noted, the water should be tested, and if found high in alkali, better sources of water should be substituted if possible.

Where the accumulation of alkali is likely to result from rise of water table charged with alkali, good drainage is essential to the prevention of injury.

Treatment.—As to the treatment of orchards already injured by alkali, only general suggestions may be made, as are given by Kelley and Thomas (1920). If saline irrigation water is the cause, the first consideration is to obtain a supply of pure water for future irrigation. Good water applied freely will tend to leach down the harmful concentrations below the root zone. If the subsoil will permit deep penetration and drainage, an occasional flooding may help in leaching the salts below the region of the roots. The use of manure or bulky organic material and cover crops will usually help to counteract the alkali effects. On some soils an application of gypsum and other non-alkaline salts may also help by increasing the porosity of the soil and allowing deeper penetration of water. The presence of an abundance of soluble calcium also appears to enable plants to tolerate concentrations of alkali salts that are very harmful in its absence. The soil should also be put into a condition previous to the rainy season to prevent run-off and to allow the rains to have the greatest possible effects by deep penetration and the leaching down of alkali accumulation.

Where saline water is the only supply that is possible to obtain, Kelley and Thomas suggest the adoption, in some cases at least, of some form of basin or flooding instead of the furrow system of irrigation. By this means, the salts may possibly be leached beyond the root zone. The nature of the subsoil drainage, however, will determine largely the success of this scheme. Flooding around the tree trunk should be avoided or used with great caution on heavy soils where bark susceptible to gum diseases is exposed to the water-soaked soil. Flooding may be coupled with the proper use of manure, cover crops and the other measures already outlined above for counteracting the effects of high alkali salt concentrations.

CHAPTER XV

ABNORMALITIES AND GENERAL EFFECTS

SPHÆROPSIS KNOT

A woody hard enlargement on the branches of lime trees, due to the fungus *Sphæropsis tumefaciens* Hedges, is common in Jamaica, where in past years it has given trouble, especially in the northern and western parts of the island. It has also been found occasionally on orange trees. It occurs as a minor disease in Cuba and the southern part of Florida. A similar disease, affecting the lime *Citrus aurantifolia*, has been observed by Lee in Java. It has not been observed there upon pummelo or mandarin orange trees. A similar disease has also been observed upon lime trees in the Hawaiian Islands. It has not been observed, however, in China, Japan or the Philippines, although lime trees are of common occurrence in those countries.

Florence Hedges, in summarizing the information obtained during a visit to Jamaica in 1906, states (Hedges and Tenny 1912): (1) that the knot appears on trees of all ages and at any season regardless of weather conditions; (2) that it spreads from tree to tree; (3) that it appears on sprouts after an affected tree is cut down; (4) that a whole series of knots is formed on an affected tree extending up the branches; (5) that from these knots an abnormal number of branches grow out; (6) that it causes trees to die prematurely; and (7) that it is most prevalent in the so-called "red dirt" soils rich in iron. The knots in Java and Hawaii are on branches from ¼ to 2 inches in diameter.

Symptoms.—The knots are usually rounded, woody, abnormal growths, at first covered with nearly normal bark, but later, with exposure of the enlarged woody tissues, becoming rough and fissured, knotty and deeply furrowed. They vary in size from ⅜ to 2 or 3 inches. A variation from the rounded form sometimes occurs as elongated swellings or as an eruption extending along the stems. At the very first, the knot is covered by bark, and, provided the growth is rapid, the bark may remain intact, smooth and light in color. When cut into, the surface of the knot is found to have a somewhat soft crumbling character as compared to the normal, firm, greenish bark of healthy branches. Inside, however, there is hard, compact, firm woody tissue. Since the modified bark of the knot is about the same thickness as normal bark, the increase in size is mainly by addition of woody tissue. The interior may be streaked with black or it may appear to be that of normal wood in color. The knots have a broad basal attachment to the branch and frequently extend laterally till they girdle the branch. They cannot be easily broken off (Figs. 100, 101).

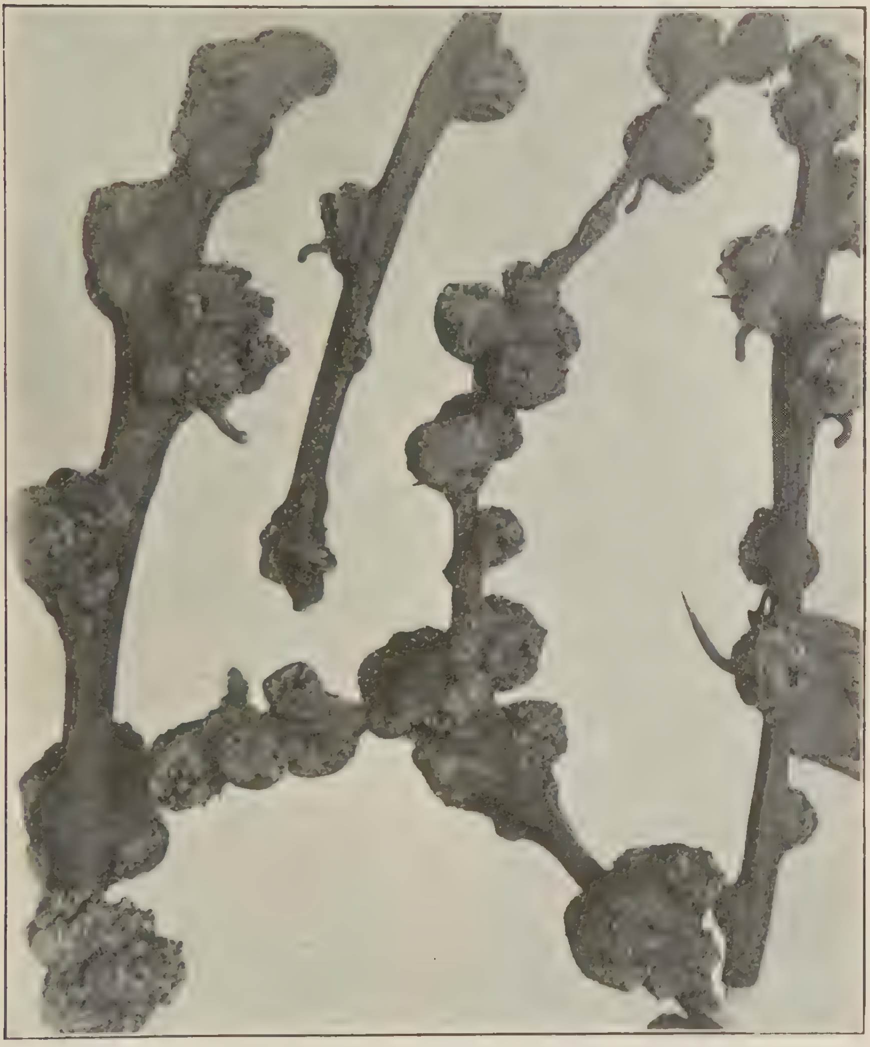

FIG. 100.—Knots due to the fungus *Sphaeropsis tumefaciens* from Cuba. (*Photo by C. O. Smith.*)

Knots usually give rise to a large number of new shoots forming "witches'-brooms." As many as thirty to forty shoots have been observed on one knot. These shoots, in turn, frequently develop knots as they grow out, and usually die back in a few months. In case the

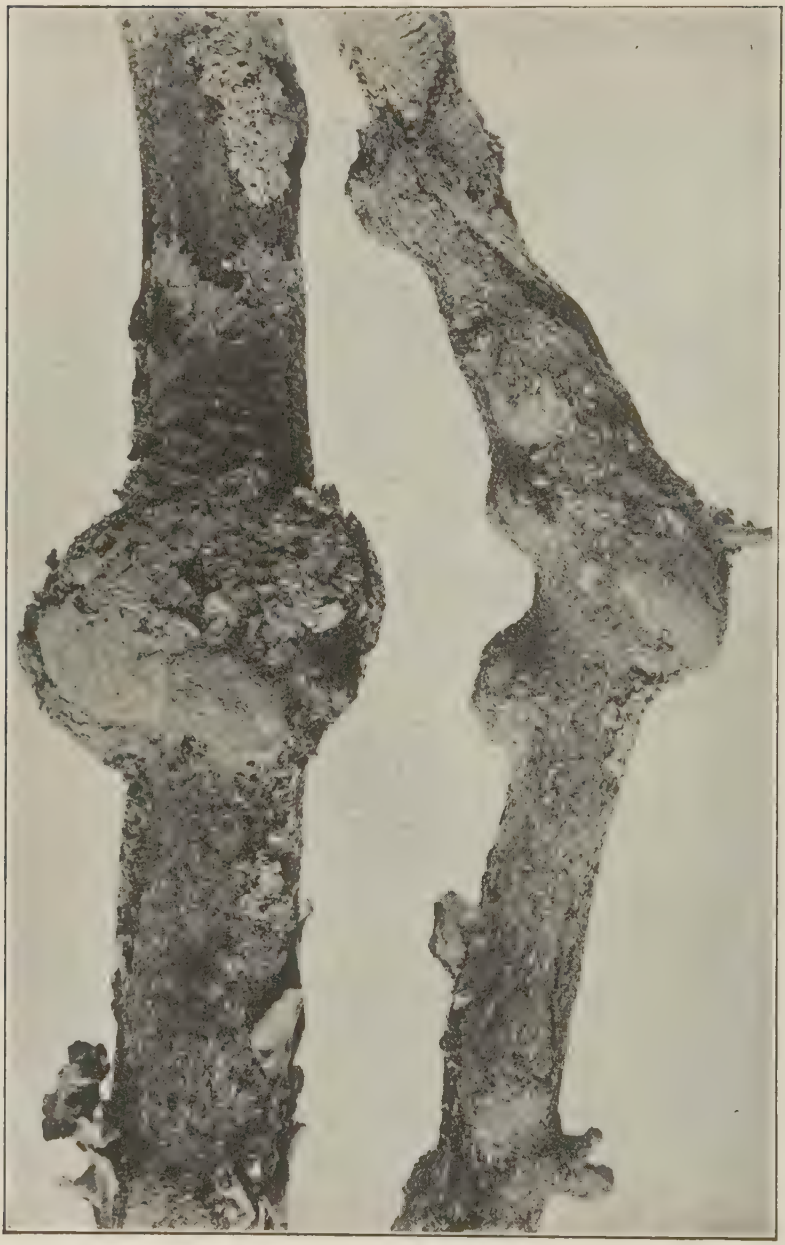

FIG. 101.—Citrus knot on lime twigs from Java.

knots are numerous and girdle a branch, the part beyond usually dies. Secondary knots may later form on the branches and trunk and, under Jamaica conditions, ultimately kill the tree. As in most fungus diseases of Citrus, gum frequently forms as a result of the disease, but is not a universal accompaniment. Under certain climatic conditions, as those prevailing in Florida, the disease appears to be of minor importance and is found only rarely in a milder form.

Causal Agent.—The causative agent in the initiation of this type of knot is the fungus, *Sphæropsis tumefaciens* (Hedges 1911). The mycelium of the fungus has been found in abundance in the cortex, where in some cases it forms an almost solid black mass, and it also occurs in the wood and the pith of some knots. In rapidly growing bud tissue on the surface of knots, the mycelium is in the intercellular spaces (Hedges and Tenny 1912). Investigations have not been made to ascertain whether or not this fungus is present in the knots found in Java and Hawaii.

According to Hedges, who has made a very thorough investigation of this disease and the fungus causing it, with numerous cultures and inoculation experiments, fruiting bodies (pycnidia) have not been found on naturally occurring knots. A few strains of the fungus, however, have been found to produce pycnidia on galls induced by inoculation in the greenhouse. The fungus within the host is usually in the form of branching septate mycelium consisting of colorless or brown hyphæ varying in size from 0.4 to 4μ in diameter. The fungus on knots from artificial inoculations is described in detail by Hedges and Tenny (1912), from whose publications the following is extracted: Pycnidia subglobose, papillate, very dark brown or black, closely crowded together or solitary with a cellular peridium, 152 to 224 by 120 to 192μ; at first buried by epidermis, but finally bursting through to surface. Occasionally found in the wood. Spores large colorless or yellowish, oblong or ovoid, rounded and both ends subacute, or rounded at one end and sharply acute at the other, 16 to 32 by 6 to 12μ. Lime and oranges are the natural hosts. Small knots have been produced, however, by inoculations on grapefruit, lemon, trifoliate orange and tangerine.

Control.—Pruning away not only the tissue containing the visible knots but also enough of the branch or stem contiguous to it to remove the causal fungus is necessary for success in controlling severe cases of Sphæropsis knot in Jamaica. The fungus may penetrate the tissue far beyond the original point of infection, forming secondary knots some distance apart with no external evidence of disease between them. Microscopic examination, however, may reveal small quantities of fungus connecting these knots. Hedges and Tenny, therefore, suggest that:

> . . . affected limbs be removed, care being taken to cut them off well below the lowest knot. Badly diseased trees should be dug out and burned, that they may not prove a source of infection to sound trees through dissemination of the spores.

Destruction by burning is important, since it has been shown that the fungus may remain alive for a long time even in the dried galls after they have been cut off. For those countries where the disease does not yet occur, entire exclusion by effective quarantine is undoubtedly the cheapest prevention.

CITRUS GALLS

Abnormal growths somewhat resembling crown gall are occasionally found on branches of Citrus trees. As a rule, these galls are found in such small numbers that they may be considered of minor importance. Galls of this type occurring in California were illustrated and described by Fawcett (1912*d*). These galls differ from the knots described by Hedges and Tenny and appear to be due to other causes. Some of them may possibly be due to the true crown-gall organism. Nowell (1923) refers to sporadic cases of galls in Dominica and St. Lucia, in which no

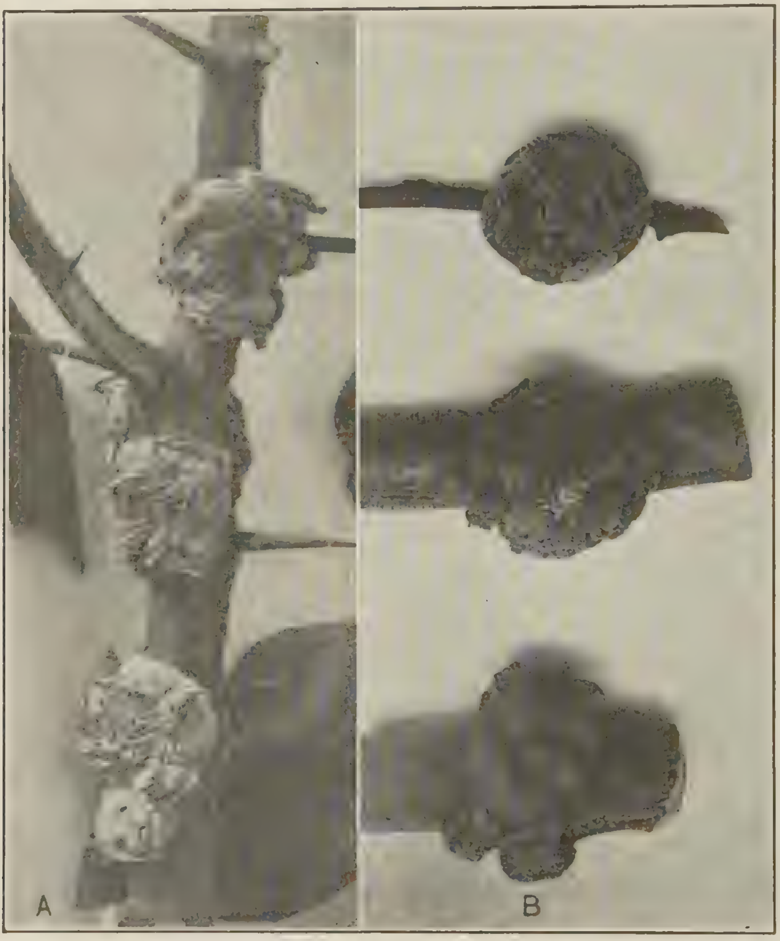

FIG. 102.—Galls on twigs and branches: A, produced by inoculation with the crown gall organism, *Bacterium tumefaciens*. (*C. O. Smith*, 1912.) B, natural occurring galls on twigs in California. (*Fawcett*, 1912*d*.)

organism could be found. Savastano refers to galls of this general type in Sicily.

The galls appear to start from one definite point on the side of a limb and to form by development spongy or woody tissue. In an early stage of formation they may have a smooth surface. Later the surface is cracked and broken, showing irregular depressions and elevations like typical crown galls of peach when produced above ground. C. O. Smith (1912) has produced galls of this same general type by inoculation with the crown-gall organism, but so far he has been unsuccessful in isolating the crown-gall organism from any of the galls found occurring naturally (Fig. 102).

Hard woody galls or knots covered by normal bark and without any sponginess of the surface and arising from a broader base have been occasionally found. These appear to be entirely different from any of those previously described. They appear to be a development of an abnormal amount of woody tissue without any special modification in the nature of the bark over it nor any serious injury to the branch on which it is formed.

Control.—Galls and knots of this type need not, as a rule, cause any concern. They may, however, be pruned out as a matter of safety in preventing any possible spread.

WITCHES'-BROOM

An abnormal growth of branches known as witches'-broom is occasionally found in Citrus trees. They occur now and again in trees in California and have been reported in Italy by Savastano (1922*b*), who states that they were observed at Palermo in 1914 and their occurrence there was traced back for fifty years. Witches'-brooms are mentioned by Reinking (1921) as occurring in the Philippines, Siam and southern China. A condition something like witches'-broom occurs also in connection with Sphæropsis knot (p. 323). These so-called witches'-brooms are often found only one in a tree or in only one tree in an entire orchard, and are more of a curiosity than cause for any alarm.

Description.—A change takes place in the nature of the growth. A shoot growing out from a normal branch becomes swollen and thick with short internodes and an abnormal number of branches. The individual secondary shoots that form are usually soft, swollen, irregular and bent or twisted (Fig. 103*a*). There are often gall like swellings at the nodes and along the secondary shoots as well. These secondary shoots become short and stubby and give rise again to an abnormal number of other short stubby shoots. The buds often die, and later the branches become weak and stunted. The leaves are often abnormal in size and shape and at times show chlorosis. The resultant growth is a thick mass of ill-shapen twigs, the so-called witches'-brooms. Many different shapes and sizes have been seen on Citrus, from small ones a few inches across, to large witches'-brooms extending several feet in largest diameter. A curious type was found originating in the position normally occupied by a lemon fruit (Fig. 103*b*).

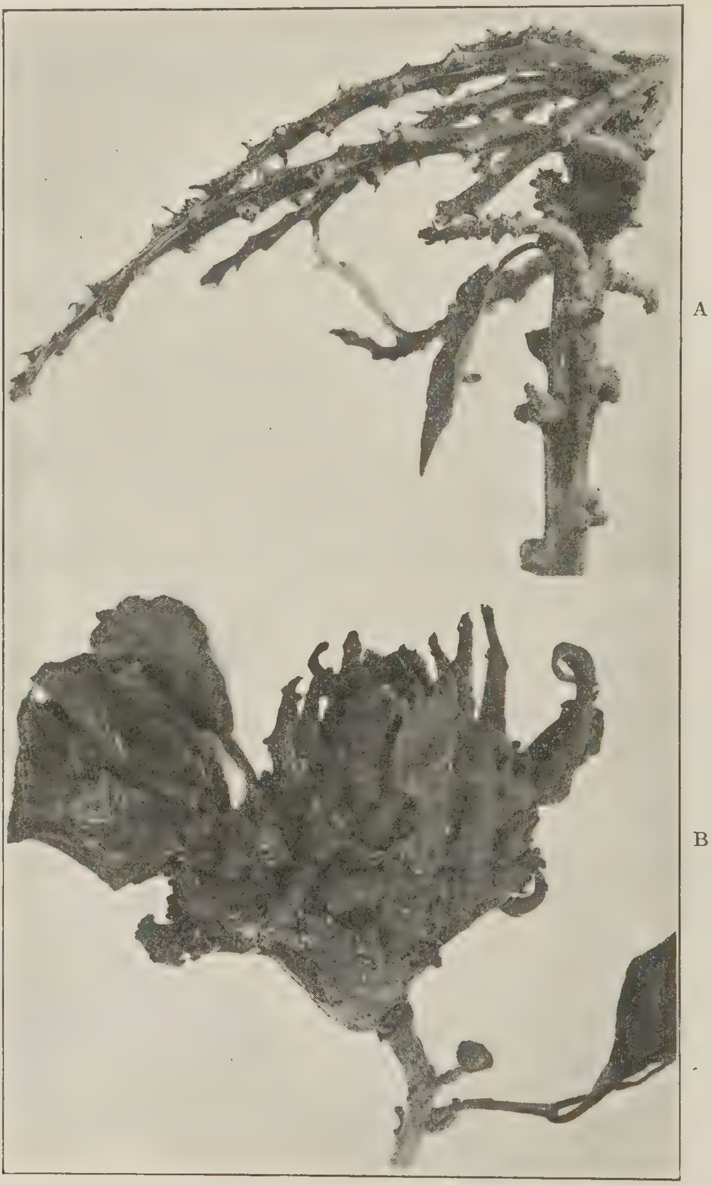

Fig. 103.—A, witches broom found developing on a pummelo tree in the Philippines. (*Photo by H. A. Lee.*) B, small witches broom developing at the end of a lemon twig where a fruit would normally be borne. (*Photo by C. O. Smith.*)

Cause.—The cause is not known for a large number of these witches'-brooms on Citrus. It is probable that some organism is capable of initiating them. One type of witches'-broom is known to originate through the influence of the fungus *Sphæropsis tumefaciens* Hedges (p. 323). This type forms from buds on the surface of the knots. Other types, however, are probably due to other organisms or other causes.

Control.—These witches'-brooms are usually so rare as to call for no definite control measure, except to prune them out whenever they are found. Some of them appear to grow so much faster than the branch from which they originate as to assume almost the nature of a parasitic growth of one part of the branch on the other.

CRINKLY LEAF

Crinkly leaf is a term applied to a condition in which the leaf blades show a kind of crinkling or pocketing. The leaves are crinkly and warped (Fig. 104). This may occur either on certain definite branches or over the entire tree. Accompanying this crinkly leaf, the fruit is frequently coarse and rough, and the surface covered with irregular bumps. This has been noted especially on lemon trees in California but is not

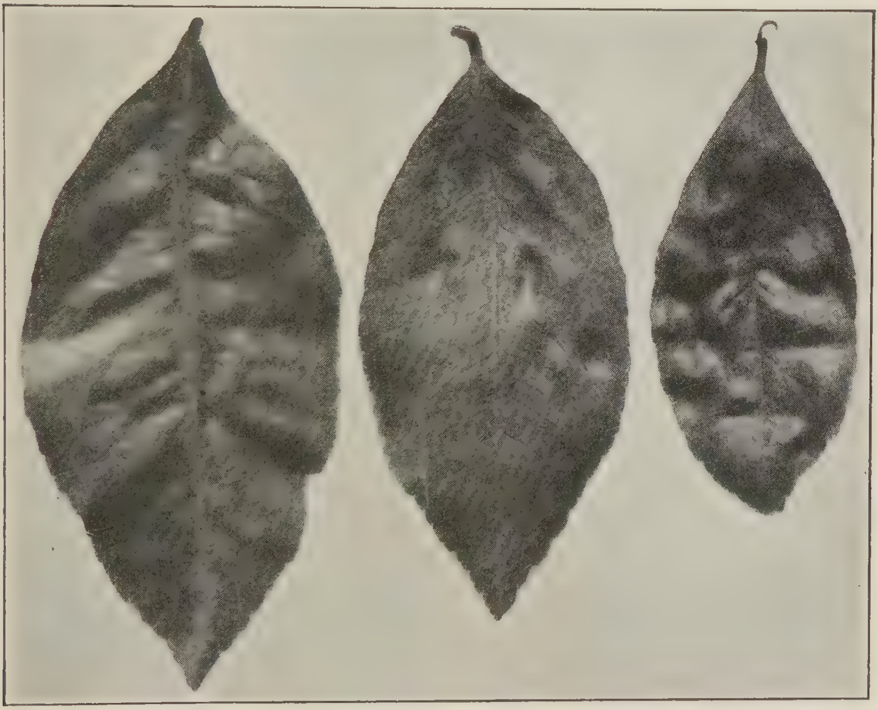

FIG. 104.—Crinkly leaf on lemon in California.

considered an important trouble. Pocketing of leaves somewhat similar to this is sometimes brought about by certain mites or other insects.

As far as known, this crinkly leaf is not a definite disease. The most common type appears to be an inherent quality of the tree or branch, something on the order of bud variation.

Where individual branches have crinkly leaf, these may be pruned out. In cases affecting the entire tree, budding over to normal buds may rid the tree of crinkly leaf.

There appears to be, however, a second type of crinkly leaf which is said to transmit this condition to new buds when they are placed on the old stocks. Nothing definite is known about the cause of this latter type of crinkly leaf.

INSECT EFFECTS

There are a number of insect injuries that are similar in general appearance to those produced by fungi or by non-parasitic agencies. It is not within the scope of this publication to describe the numerous insects and their effects on Citrus trees. Some of the more important ones, however, will be briefly discussed here, since they frequently have a relation to diseases and since their effects may be confused with similar effects of microorganisms. Moreover, a number of these insects are subject to diseases due to the attack of fungi which, on the surface of Citrus leaves, branches and fruit, often form pustules that may be mistaken for fungus diseases of the plant itself. Scale insects and white-fly larvæ are mentioned in Chap. XII.

Red-spider Injury.—Several species of mites known as red spiders produce effects on leaves and sometimes on fruit that have been frequently mistaken for fungus diseases. Their injury oftentimes opens up the way for the attack of various disease-producing fungi or bacteria.

One species of red spider, *Tetranychus citri*, causes the leaves to lose their natural glossy green and to show whitish irregular spots or specks where the insect has withdrawn the sap from the tissues. These grayish or whitish spots or dots may also show upon the fruit. This mite is especially troublesome in dry weather. When very severe, it may cause defoliation, and when the injury is followed by dry winds, even twigs and branches may be killed back, and gum exudes copiously from the axils of the dropped leaves.

The effects of another species, *T. sexmaculatus*, is to form yellow areas on the under surface of leaves, where webs containing the mites are located (Fig. 105). Later this yellow spotting becomes large; the old leaves may turn yellow, curl and fall off.

Aphids.—Certain species of aphids or plant lice cause the leaves to curl and the young shoots to become deformed so as to resemble effects that might be mistaken for a disease due to microorganisms (Fig. 106).

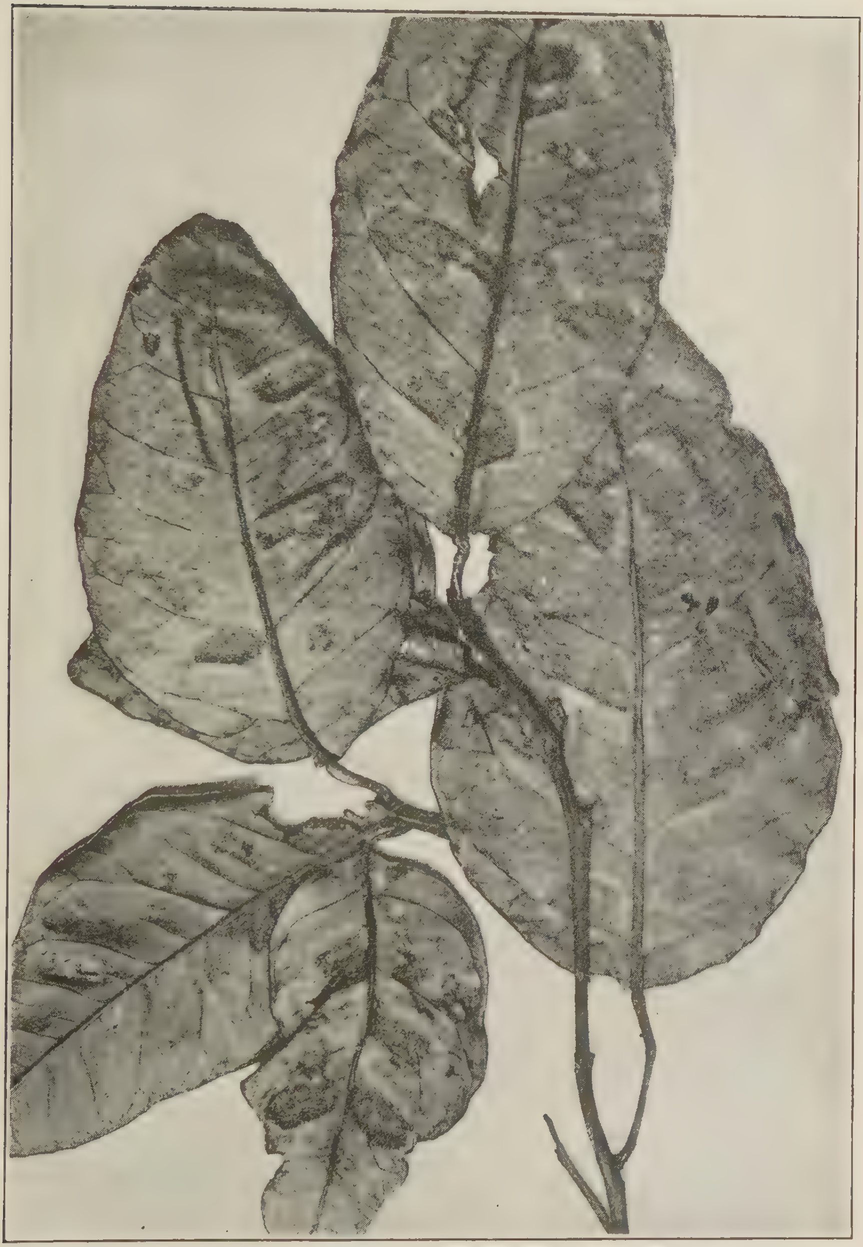

FIG. 105.—Spots due to effects of yellow or six spotted mite, *Tetranychus sexmaculatus*. (*After Quayle* (1915).)

The aphids cause not only a loss of sap but apparently produce a toxic effect upon the young growing tissue. The insects also secrete an abundance of honey dew in which the sooty-mold fungus grows and covers the foliage, as when scale insects are present. These aphids may increase very rapidly and also disappear rapidly because of the

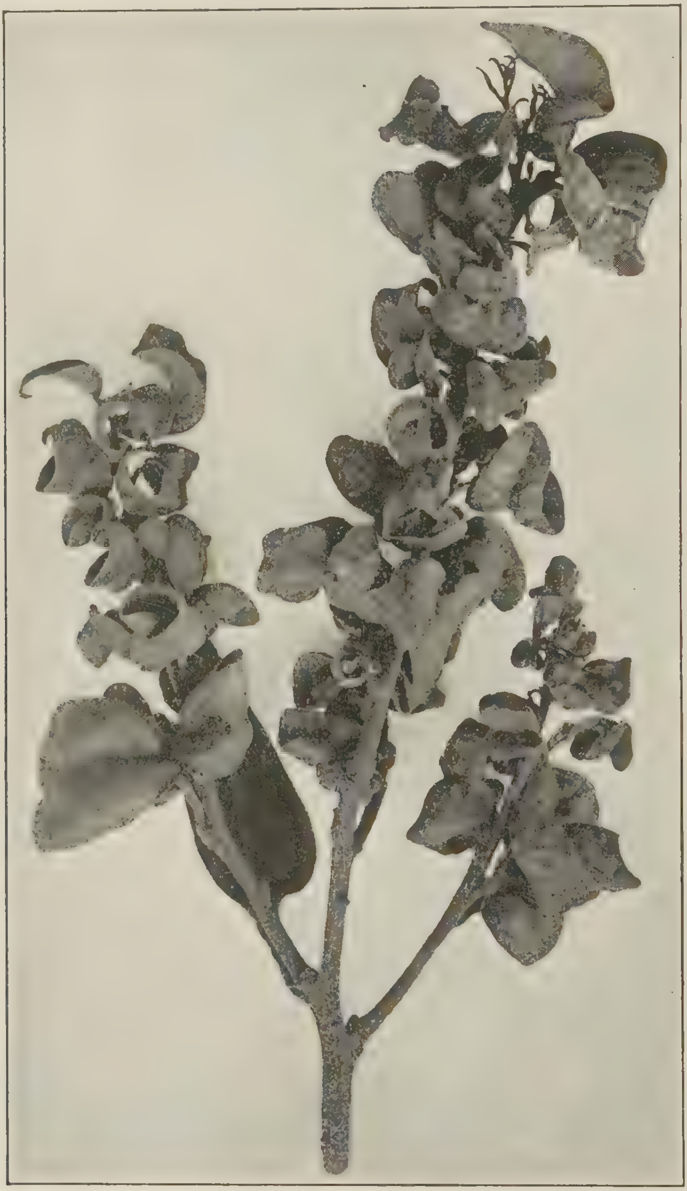

Fig. 106.—Warping of leaves due to Aphis attack in California. (*After Woglum* (1924).)

attack of certain parasites. The species most common on Citrus in California is the black Citrus aphis, *Toxoptera aurantii.* There are said to be at least five other species on Citrus in California. Recently a species known as *A. pomi* (*A. spiræcila*) has become very abundant in Florida and is causing much damage to Citrus foliage, especially on the mandarin varieties.

Psylla.—This insect produces a conspicuous curling and malformation of Citrus leaves in certain localities in South Africa. It is reported to be minor in importance but troublesome, especially on nursery stock. A small pit-like depression forms where the insects settle, and later a swelling occurs on the opposite side, producing a small open gall. When very severe, the leaves tend to curl. The leaf blade, however, remains green and appears to function in the normal way. The leaves do not appear to die or fall off badly as a result of the attack. It is reported to be coextensive with areas of summer rainfall. Hot, dry conditions appear to control it.

Leaf Miners.—The larvæ of certain species of insects known as the leaf miners burrow just under the epidermis of the leaves and succulent twigs of Citrus trees and sometimes are the means of infecting the leaves and twigs with various parasitic organisms. Where Citrus canker is prevalent, the infection may occur along the tracks of their progress. The effects usually extend along irregular tracks or lines through the surface tissue, which turns grayish or whitish in color. This effect has been noted by various writers in various Citrus countries and is not usually of common occurrence or considered highly important.

Leaf-cutting Ant.—A pest that is quite severe on the leaves of Citrus trees in certain countries is the leaf-cutting ant. In Cuba, a species known as *Atta insularis* may in the course of one night completely defoliate a number of Citrus trees. The ants use the leaves in making a pulp for culture media for a certain species of fungus which they cultivate with great care for their food in underground nests. The nests are usually located in the woods or uncultivated lands and the ants may travel great distances to certain chosen trees, which they defoliate, carrying the pieces of leaves raised over their heads. The ants look after their fungus gardens with the greatest of care and are said to weed out all contaminating fungi or molds, and to nip off the vegetative hyphæ so as to cause the chosen fungus to produce a particular enlarged growth which they use for food.

The most common method for combating these ants in Cuba is through the use of carbon bisulfide poured into their nests.

Fuller's Rose Beetle Injury.—Leaves on Citrus trees are often found to have irregular areas missing around the margin of the blades. Sometimes the leaves may be badly eaten and a large part of the leaf tissue destroyed. The larvæ produce lesions on the roots often mistaken for a fungus disease (p. 118).

CHLOROSIS

Chlorosis is a general term applied to a condition of Citrus leaves in which, instead of the normal green, there is a yellow, light yellow to almost white color. Chlorosis of one kind or another probably occurs in all countries where Citrus is grown. It is apparently a nutritional or physiological condition, the causes for which are still involved in much uncertainty. In some cases, it is probably due to inability of the leaf to get sufficient iron; in others it is probably related to inability to get other elements, as calcium, magnesium or potassium, and in still others is related to excessive amounts of certain elements taken up by the plant.

Symptoms.—Several types of partial and almost complete yellowing of leaves are common. The type of partial chlorosis known as mottle leaf, or foliocellosis, in which irregular spots occur between the lateral veins, is discussed later (p. 338) under that term and will, therefore, not be included here. Another type which has been produced experimentally by Reed and Haas (1924) is due to magnesium deficiency, where a stripe or band forms on each side of the midrib. This stripe arises from a previous series of small yellow areas a short distance each side of the midrib (Fig. 107A). A more or less uniform yellowing, taking place gradually without the entire loss of chlorophyll, may arise apparently from nitrogen starvation. Yellowish brown chlorotic spots, less than 1 millimeter in diameter, slightly raised on the under surface, usually beginning at oil glands surrounded by chlorotic area 2 to 5 millimeters where chlorophyll has disappeared, have been found by Reed and Haas on leaves of Citrus trees growing in nutrient solutions with very low calcium; the loss of chlorophyll shows on both sides.

The term chlorosis more specifically applied to Citrus is a condition in which a complete or nearly complete yellowing spreads rather uniformly over the tissue of the entire leaf. This type is found on soils underlaid with marl or limestone. It has been observed that wherever the pronounced chlorosis of this type occurs in California, there is also a high percentage of calcium carbonate in the soil—to the extent of producing effervescence when weak acid is applied to it. In severe chlorosis, all the leaves lose their green color and become colonial buff to Reed yellow. In this type of chlorosis, the veins appear to be the last to lose their green color (Fig. 107B). Other types have been observed in connection with gummosis or other effects in which the veins are the first to become yellow.

Theories as to Cause.—The type of chlorosis in soils underlaid with marl or limestone is probably due to the inability of the tree to get sufficient iron, an element essential to the formation and activity of the chlorophyll. The following explanation has been given by Lipman (1921): The presence of excess of lime as calcium carbonate brings about an excess of alkalinity (hydroxyl ion) around the soil particles. Under such conditions, the iron of the soil solution is precipitated and the roots fail to get it. Since iron is essential in the formation of the green matter or chlorophyll, this lack causes them to become chlorotic. The types of chlorosis in soils not high in calcium carbonate are probably due to other

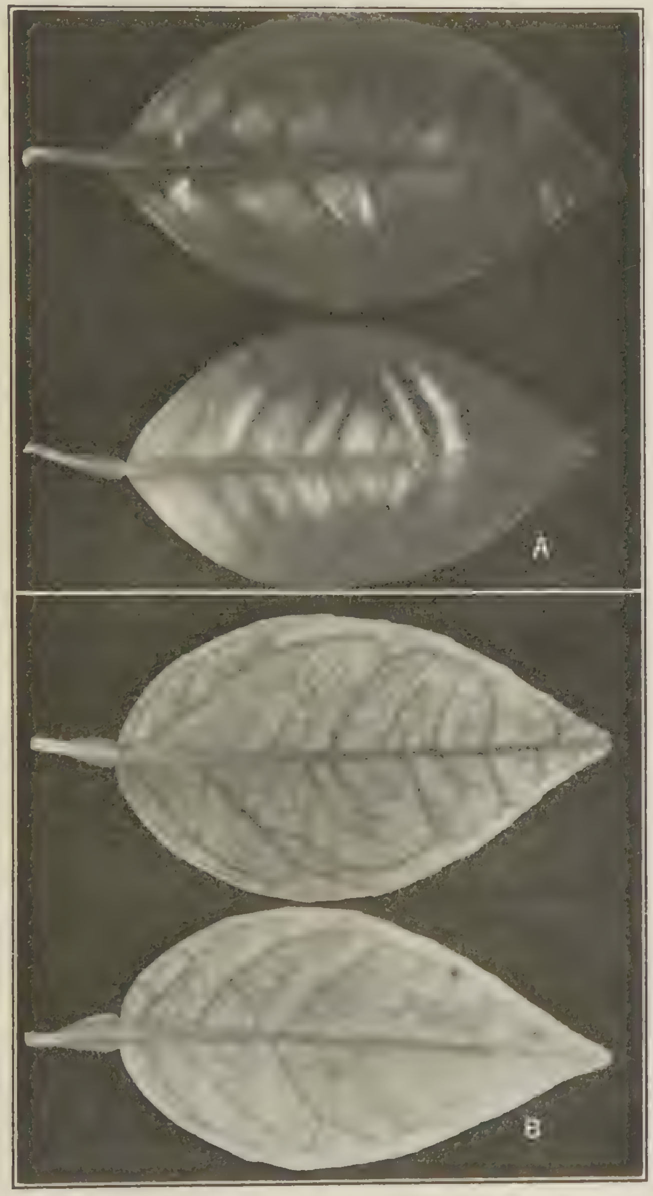

FIG. 107.—A, partial chlorosis resulting from lack of magnesium. B, chlorosis resulting from high sodium bicarbonate with low calcium. (*After Reed and Haas* (1924).)

causes. Nitrogen starvation may bring on a yellowing sometimes spoken of as chlorosis of a more gradual, less severe type, which is more easily corrected than the other.

Control.—The correction of definite chlorosis on soils high in calcium carbonate is sometimes affected by the application of manure or bulky organic matter to the soils or by the planting of cover crops to keep up a process of decay. The explanation for this influence, as pointed out by Reed and Haas (1924), appears to be that the decay of organic matter has a solvent action upon the iron as well as producing carbon dioxide. This action probably brings iron into solution and thus enables the tree again to get adequate quantities for the formation of the green matter in leaves subsequently formed. The corrective effect will be seen in the new growth and not in leaves that have matured while they were chlorotic.

The application of iron compounds to the soil where chlorosis is related to high alkalinity has usually not corrected this type of chlorosis. The precipitation of iron in soils of high alkaline reactions takes place so rapidly that it is usually not available to the tree. The application of iron compounds to chlorotic Citrus leaves in experiments so far carried out appears to cause them to turn green only in certain small spots. Recent experiments in the injection of Citrus trees with iron sulfate is reported by Lipman (1925) to be a corrective for chlorosis.

It has frequently been observed that trees do well in Florida on coquina-rock soils so long as the soil is constantly supplied with organic matter in the form of grass, weeds or cover crops, but that as soon as the soil becomes depleted of such matter the trees turn very pale and the leaves become very chlorotic. Most soils have already an adequate supply of iron if the conditions are such as to bring it into solution. The use of the proper amount of manure, bulky organic matter or cover crops helps not only to make the iron soluble, but supplies nitrogen for making growth and for correction of partial chlorosis due to nitrogen starvation. Care should be exercised, however, not to use too much of certain kinds of organic nitrogenous fertilizers on certain Florida soils, since an excess appears to be associated frequently with the occurrence of exanthema and other disturbances.

FOLIOCELLOSIS

A condition of partial chlorosis which has been known as mottle leaf in California and frenching in Florida appears to be present in varying degrees in all countries where Citrus is grown. The term foliocellosis is suggested as a convenient name. It appears to be a nutritional effect probably related in some way to the inability of the tree to satisfy its calcium requirements. The disease gets its name from its effect on the leaves, but in severe cases it affects indirectly the size of the fruit, growth of branches and finally the entire tree.

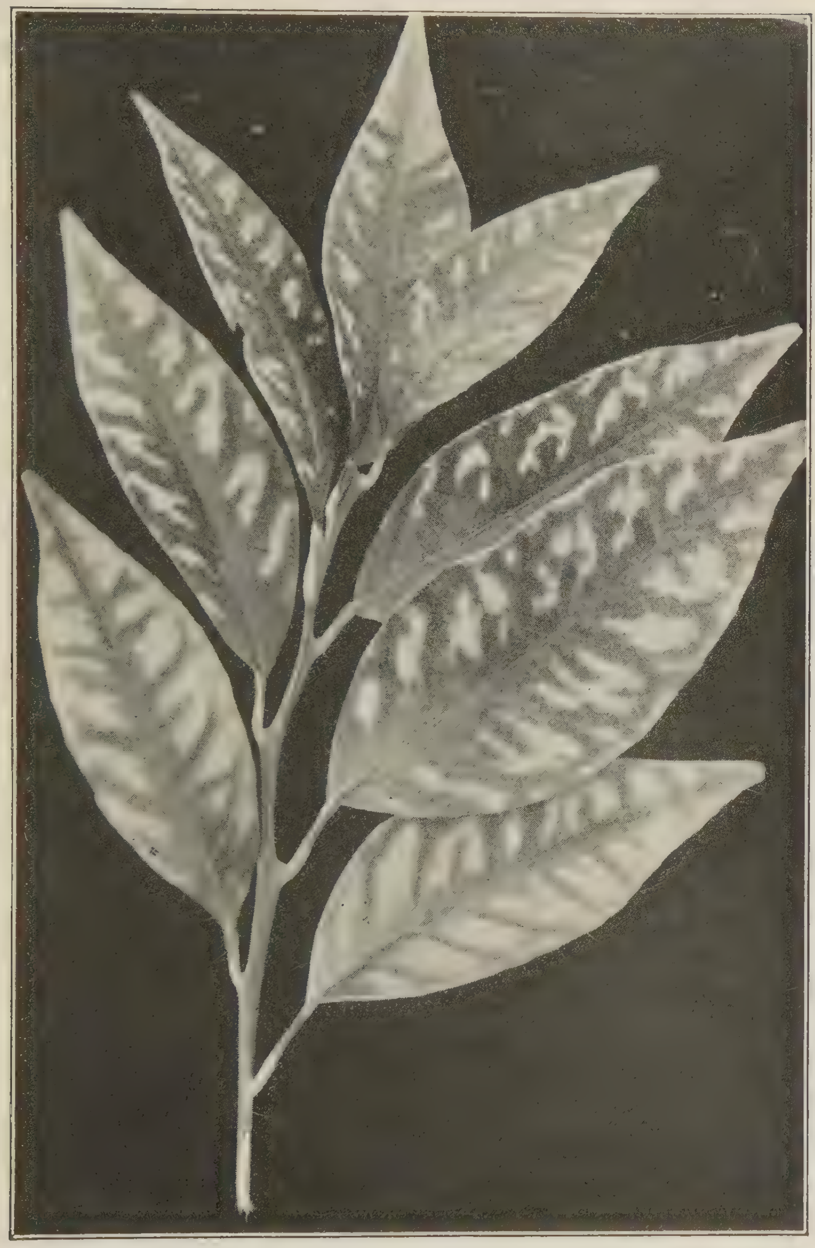

FIG. 108.—Foliocellosis on orange leaves in California. (*Photo by C. O. Smith.*)

Symptoms.—The leaves show chlorotic areas, irregular in outline, situated between the main lateral veins on each side of the midrib. The part immediately next to the large veins and midrib remains green, while the green matter is lacking in portions between these. This results in an irregular spotting or mottling (Figs. 108, 109). In trees only slightly affected, this may occur on leaves of normal size and without much effect on the tree or crop. When more severe, however, the leaves mature smaller in size, and in the worst stages of the malady they are usually not

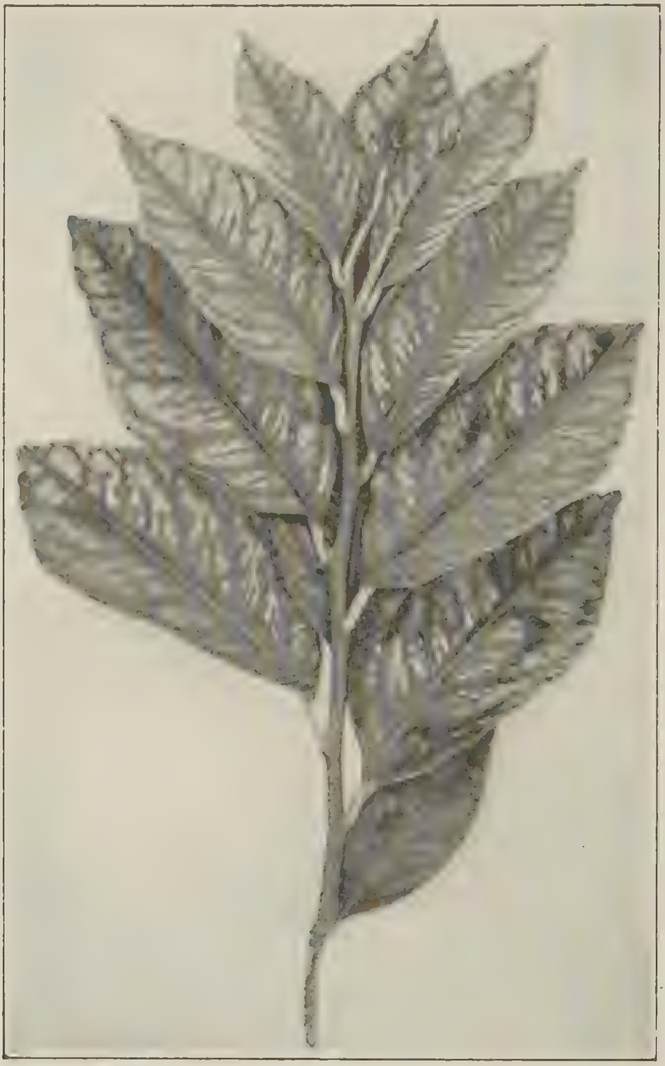

Fig. 109.—Foliocellosis on lemon leaves in California. (*Photo by C. O. Smith.*)

only very small but extremely narrow as compared to healthy leaves. In such cases, the fruit is very small, often elongated, pale yellow in color, poor quality, coarse and frequently known as "small offs." The whole tree may become densely branched and stunted, with the twigs dying back from the tips. Following this repeated dying back of the tips, multiple buds appear as in exanthema, and a bushy type of growth often results.

Theories as to the Cause.—The explanation for the cause of foliocellosis in Citrus is still involved in much uncertainty. Recent investigations, however, have led to a tentative explanation for some of the direct and indirect factors involved. Citrus trees require, for their normal growth, a large amount of calcium. Whatever conditions within or outside the tree tend to hinder sufficient calcium from getting to the leaf probably contribute indirectly to foliocellosis. It has been found by Kelley and Cummins (1920) that mottled leaves are low in calcium as compared to normal leaves. Reed and Haas (1924) have shown that symptoms closely resembling foliocellosis may be induced under controlled nutrient conditions where calcium is insufficiently supplied to young trees in tanks, especially when potassium is high as compared to calcium. When the absorption of potassium or other monovalent cations is unduly large in comparison with that of calcium, a condition is brought about which appears to be favorable to the disease.

Reed and Haas have also pointed out how this deficiency of calcium might operate in the leaves to influence the occurrence of foliocellosis. An excess of acidity in the leaf sap accompanies this condition (Kelley and Cummins 1920), and it is possible that this lack of calcium in mottled leaves is partially responsible for the accumulation of unneutralized acids. Since the areas first involved in the mottling are farthest away from the main veins of the leaf, these would be the first to be affected by an inadequate supply of calcium as it moved into the leaves.

Contributing Conditions.—The indirect causal factors which operate to bring about mottling of the leaves appear to be many and complex. Under irrigated conditions in California, foliocellosis is very common on some soils, varying in intensity from slight in certain seasons to a severe permanent stunting of the tree. It varies somewhat with the season of the year, usually being more pronounced during the dormant period when the leaves are fully matured.

Any condition within the tree itself which would prevent an adequate supply of calcium from getting from its roots through the trunks and branches to the leaves might, of course, be a factor in inducing the disease. Lee (1921*a*) has found that a given variety, as, for instance, the Valencia orange, is more susceptible to foliocellosis when grown upon a pummelo stock, *Citrus maxima*, than on sour-orange stock, *C. aurantium*, when growing under the same conditions of soil. Miller (1919) mentions the influence in producing mottling on lemon trees when roots from the lemon bark are allowed to grow out from above the bud union. The influence of rough-lemon stock in producing mottled leaves on lemon trees budded thereon has frequently been noted in California under conditions where this was not apparent on trees budded on sweet- or sour-orange stock. It has been commonly observed also that in certain soils in California the Eureka lemon is more subject to the malady than the Lisbon on the same stock. The question arises as to whether certain varieties of stocks or scions or combinations of the two do not have greater difficulty in getting an adequate calcium supply to the leaves than others.

Some of the contributing conditions in the soil that have been offered in the past as an explanation for the cause of this disease are lack of organic matter in the soil (Briggs, Jensen and McLane 1916), the continuous use of nitrate of soda as a fertilizer and the accumulation of alkali salts (Kelley and Thomas 1920), the presence of severe infestation of Citrus nematodes (Thomas 1913), severe pruning or beheading of trees, etc. None of these conditions, however, acting alone would necessarily produce the disease, but possibly only when they act in the nutritional complex in such a way as to prevent the tree from satisfying its calcium requirements.

Remedial Measures.—The following tentative suggestions are based on the theory that foliocellosis is related to the inability of the tree to satisfy its calcium requirements, which theory has had support by the recent investigations previously referred to.

On first thought it might be supposed that the remedy would consist simply in the addition of certain calcium compounds to the soil. In soils actually deficient in calcium and which are at the same time acid or neutral in reaction, such procedure may be beneficial provided the substance added does not produce excessive alkalinity.

On soils with an alkaline reaction, however, calcium may already be abundant and yet the tree not be able to get sufficient to satisfy its needs. On such soils the addition of any substance (such as calcium carbonate for example) which tends to make the soil reaction more alkaline, would, at the same time, tend to decrease the availability of calcium. The remedy in such a case would appear to lie in the employment of practices that tend to neutralize this alkaline reaction in the soil so that the calcium already present or which may be added may become available. Only substances or practices resulting in greater acidity rather than greater alkalinity should therefore be used on such soils. For this reason, the addition of stable manure, bulky organic matter and cover crops are beneficial on many such soils because the processes of fermentation and decay set up tend to increase acidity and consequently tend to increase the availability of calcium.

Since it is only in subsequent growth that normal leaves can again be obtained, it is necessary that the tree have sufficient nitrogen for the production of new growth.

THE PARASITIC FLOWERING PLANTS

MISTLETOES

The green parasitic flowering plants of the family Loranthaceæ which grow as parasites on woody plants are usually known as mistletoes. The most commonly known mistletoes belong to the genus Phoradendron. Some of the genera that have been reported as parasites on Citrus trees are Loranthus, Dendropemon and Struthanthus.

Loranthus.—At least three species of Loranthus are recorded as parasitic on Citrus species: *L. philippensis* is of very general occurrence on Citrus trees in the Philippines and has been known there since 1845. *L. parasiticus* is recorded on Citrus trees in southern China and Siam by Reinking (1921). A species of Loranthus is also very commonly parasitic on Citrus trees in Java and Ceylon. *L. calcycalatus* is recorded by Gandara (1910) in Yucatan. Loranthus on Citrus has also been reported in Rhodesia. The species of Loranthus are of very wide distribution in both the western and eastern hemispheres, but are most commonly found in the tropics or in warm sections of temperate-zone countries.

Description of the Parasite.—The Loranthus species parasitic on Citrus are shrubs with elongate, slender branches; the leaves are opposite, narrow, tomentose, coriaceous, olivaceous, with short petioles, and impress one as rather dry. They occur at any stage of the growth of the Citrus trees, near the base or well up in the tree tops. The flowers of the parasite occur at the axils of the leaves and are solitary, slender, cylindric, of brownish-yellow or yellowish-white color. There is little difficulty in identifying this plant when found parasitic on Citrus trees.

Contributing Conditions, Nature of Injuries and Prevention.—The parasitizing of Citrus trees by Loranthus is usually found in poorly kept orchards where little or no pruning or other attention is given to the trees. The occurrence of these parasites only in tropical countries of high temperatures, abundant rainfall and humid atmospheric conditions, such as Java, Siam, southern China and the Philippines, leads to the inference that in dry, colder countries little or no difficulty is to be expected from these parasitic plants.

The injury from these parasites is not severe, although one or several small limbs may be affected at one time. Affected limbs first form fewer and smaller leaves, fruits which may be formed are dropped and the limb becomes unproductive. With time the limb dies back from the tip, and the parasite assumes the form and appearance of the branch. In trees which are severely affected, the tree will have a partially denuded appearance, with clumps of the greener, thicker foliage of the parasite noticeable throughout the tree top.

No experiments have been carried on for the prevention of the attacks of these parasites, but it is usually recommended that affected branches of the host be pruned out and the sources of seed for more extensive spread of the parasite be thus eliminated. In carrying out such elimination of sources of seed, woody growth nearby the orchard should also be inspected to eliminate the sources on other nearby host plants.

There does not seem to be any great probability of any serious losses from these parasites in such temperate-zone Citrus-growing countries as Japan, Australia, California, Florida or the Union of South Africa, where, in addition to the fact that the climate is unfavorable to their development, orchards for the most part are carefully pruned and given other cultural attention. The wide distribution of Loranthus species throughout the world and the ready cognizance of the parasites from their gross character make the possibility of their entrance into a new country extremely remote.

Dendropemon.—Stevenson (1918*a*) mentions two species of Dendropemon, *D. bicolor* and *D. carbiæum*, as occurring on orange and grapefruit trees and many other hosts in Porto Rico. Nowell (1923) mentions the latter species as very abundant in semineglected lime trees in Dominica. These plants are often widely disseminated by birds which carry from tree to tree the sticky-coated seeds that adhere closely to the branches where they germinate and send root-like processes into the bark. Hence, this and other mistletoes are often known as bird vine. The limbs are frequently killed beyond the point of entrance of the parasite.

Struthanthus.—Nowell (1923) mentions *Struthanthus dichotrianthus* as a pest of orange trees in Trinidad where numerous species of the same genus occur. This mistletoe is said to be peculiar in possessing aerial roots which extend over the surfaces of the branches of the host and thus rapidly promote the growth of the parasite. The same method of eliminating the parasite as that suggested for Loranthus is applicable to Struthanthus and Dendropemon.

Dodder or Cuscuta

The dodder, also known as vermicella and love vine, belongs to the genus Cuscuta of the family Convolvulaceæ. A number of species of this parasitic flowering plant have been found on Citrus. It is mentioned by Stevens (1918*a*) in Florida, Gandara (1910) in Mexico, Hauman-Merck (1915) in Argentina and by Nowell (1923) in the West Indies. It has also been seen frequently in California.

The dodder appears as a small, yellowish, vine-like plant which entwines itself tightly around the plant and sends out root-like processes which penetrate the bark at intervals. When it becomes very abundant on the tree, it may weaken it and cause the growth to be stunted. On nursery trees in California, it has been observed to result in gall-like extensions from the bark (Fig. 2). The seeds germinate on the ground, but after the plant has grown up and becomes established, the connection with the soil disappears and it gains its nourishment from the host plant.

Stevens (1918*a*) suggests that the dodder on wild plants in the vicinity of Citrus trees likely to become infested, should be destroyed. Nowell (1923) refers to the use of 0.5 per cent sulfuric acid or 2.5 per cent copper sulfate to destroy dodder. These strengths could probably not be used on a Citrus tree without injuring the foliage and twigs. The trees should be watched for the first appearance of dodder so as to destroy it before it has had time to spread throughout the tree.

CASSYTHA

Cassytha of the family Lauraceæ is a vine-like plant closely resembling dodder. It has been mentioned by Stevens (1918*a*) as occurring on Citrus in southern Florida. Its twining stems are more wiry than dodder and more finely striated. The stems are also of a dull-greenish color. It is reported to grow more vigorously and to make a looser growth than the dodder. Stevens reports that when long neglected, it may entwine the entire head of a tree, badly stunting its growth. The remedy suggested is the removal of as much of the vine as possible.

PART IV

FRUIT DISEASES

INTRODUCTION AND IDENTIFICATION KEY TO FRUIT DISEASES

The fruit diseases, considered in a broad sense, in relation to effects on the tissues or parts of the fruit itself and made to include all blemishes and results of insect attack, climatic, mechanical and physical effects, as well as attack of microorganisms, fall naturally into three main groups:

1. Definite decay or rots, which are soft or pliable in their general effects.
2. Internal derangements apart from definite decay.
3. External spots, markings, scabs, hypertrophies or eruptions within the rind or upon its surface. In general, the diseases will be grouped for convenience of identification into these rather arbitrary divisions. Viewed in relation to the causal factors or agents, they would, of course, have an entirely different grouping.

Key to the Fruit Diseases

PAGE

I. True rots; in the later stages usually involving the entire fruit:

A. Soft and easily punctured by slight pressure of the finger:

1. Forming olive-green powdery masses of spores on the surface, but no green color in the spongy portion within—
   Common green mold 353
2. Forming blue powdery masses of spores on the surface, and later also a blue color in the spongy portion within—
   Blue-contact mold 357
3. Forming salmon-buff to buff-pink masses of spores; in mixtures with certain other fungi forming red masses—
   Pink mold 362
4. Forming at high temperatures a layer of black spore masses on the surface—
   Aspergillus rot 365
   Rhizopus rot 366
5. Very soft, sour, putrid, watery rot causing tissue of fruit to disintegrate and collapse with liquid escaping. Growth of fungus appearing as if water soaked. Light buff to yellowish buff—
   Oöspora or sour rot 369
6. Developing at high temperatures on fruit near the ground. Soft mummy brown to dark brown at first, with formation later of small cinnamon-brown spherical sclerotia $\frac{1}{50}$ to $\frac{1}{25}$ inch (0.5 to 1 millimeter) in diameter. Cuba and Porto Rico—
   Rolf's Sclerotium rot 367
7. A brown to blackish-brown interior rot of lemons spreading along the core and inner rind from the stem end. Later showing through to the surface as olive brown or fawn brown with finally a collapse of the entire fruit—
   Alternaria or "center rot" of lemons 389

PAGE

8. Beginning as a pliable stem-end or stylar-end rot, but soon becoming quite soft. Mostly on lemons, may be various shades of brown to almost black—
    Alternaria rot of lemon 389
    Anthracnose rot 396
    Fusarium rot 398

B. Leathery, pliable rots not so easily punctured by pressure of the finger, nor usually so soft as the preceding:

1. Beginning in the orchard or storage as firm, ill-defined spots not sunken. Starting on any portion of the rind. Becoming brown to drab. Developing a characteristic penetrating odor—
    Pythiacystis rot or brown rot 372
    Phytophthora rot 379
2. Producing hyaline or water-soaked firm areas usually found on the *Natsu mikan* (summer orange) in Japan while fruit is on the tree—
    Hyaline rot 388
3. Beginning as hyaline to drab sunken areas at stylar end, involving one-fourth to one-half of the fruit. On Persian limes—
    Stylar-end rot 399
4. Beginning as firm spots of pinkish brown, cocoa brown to buff brown followed by white mold, which produce clumps of yellowish-green to bluish-green spores.
    Trichoderma rot 364
5. Beginning as leathery pliable areas light cinnamon brown to dark brown on lemons, medium to dark yellowish brown on oranges followed by surface mold with light neutral-gray to dark-gray spore masses. Spreading by contact—
    Botrytis rot 385
6. Beginning as a lighter-colored, leathery, pliable area than the last, dark buff yellow on lemons, becoming yellowish brown to greenish brown, followed by cottony mold and black seed-like sclerotia. Spreading rapidly by contact—
    Sclerotinia rot or cottony rot 380
7. Beginning typically as a leathery pliable stem-end rot with various colors:
    a. A gradual discoloration advancing from the stem end, with various shades of drab and brown. Can usually be separated from the next rot with certainty only by use of cultural methods—
        Phomopsis stem-end rots 401
    b. Like the last at first but usually becoming darker and with a stronger odor. With more of a tendency to darken the interior and advance along the divisions forming dark bands—
        Diplodia rot 409
        Dothiorella rot 412
    c. Slowly developing; mummy brown to sepia or black in color; sometimes with minute pink to black pustules on the surface. Frequently (not always) dark to black inside. Often becoming soft and easily punctured. Variable and often associated with other rots—
        Anthracnose rot 396
    d. Light cinnamon brown to dark brown on lemon, medium to dark brown on orange. Beginning stage of—
        Botrytis rot 385

PAGE

e. Pinkish brown or cocoa brown, very firm. Beginning stage of—
Trichoderma rot 364

f. Olive brown or fawn brown, leathery, pliable at first, soon becoming soft and easily punctured. One form of—
Alternaria rot 389

C. Rots more firm and dry in consistency but usually involving a part or the whole of the interior:

1. A mummy brown to black dry rot usually in or near the stylar end, especially on navel oranges, but may affect other varieties; may become somewhat soft in storage or transit—
Alternaria or black rot of oranges 393
2. A firm, dry stem-end rot, dark brown to almost black in color, usually on lemons—
Pleospora rot 393
3. A mealy dry condition of the interior leading to a dry rot with a disappearance of juice and thickening of the walls of the membranes and vesicles. Philippines and West Indies (see also II-6)—
Inspissosis or dry rot 415
4. A black and granular condition of the interior, which has resulted from an inward extension of reddish-brown to black spots on the exterior; on mandarin orange. Italy—
Cytosporina rot 465
5. On limes. At first a deep-yellow to copper color of the exterior with abnormal odor and taste. On mummified fruit, the interior is filled with black, hard masses of mycelium—
Charcoal rot of limes 414

II. Internal drying or deterioration. Usually not true rots, but often opening the way for the rots previously mentioned:

1. Breaking down or drying of internal tissues back of the stylar end accompanied by pinkish to rust-brown discoloration and sometimes gum formation. In lemons—
Endoxerosis or internal decline 421
2. Empty cavities formed by pulling away of tissues at the core of lemon fruits—
Hollow core 426
3. Staining of membranes or carpellary walls and sometimes the core in irregular areas dark yellowish brown, dark brown or sepia without visible breakdown of tissue. Mostly in lemons—
Membranosis 428
4. Water-soaked areas on the internal membranes, or white spots containing crystals of hesperidin followed later by drying out of pulp—
Frost injury 429
5. A stiffening and granulation of the juice sacks beginning at the stem end of mature oranges and giving the impression of a crystalline structure. Juice sacks hard and firm instead of flabby—
Juice-sack granulation 426
6. Mealy, dry condition of interior with disappearance of juice and thickening of walls in mandarin oranges in Philippines. (Likely to be sought for here but belonging logically in *I-C*)—
Inspissosis or dry rot 415

PAGE

7. Gum formation at the angles of the segments near the core; often accompanied by staining on the exterior—
    Exanthema.. 501

III. Spots, usually sunken below the surface of surrounding normal tissues of the rind:

A. Sunken spots, more or less deep seated in the rind, usually involving more than a superficial layer. Spots from various causes are often similar and difficult to separate:

1. Spots of various sizes, brown to almost black, dry to pliable and leathery. Mostly on very mature oranges, grapefruit or lemons in the orchard. Sometimes enlarging in storage—
    Anthracnose spot.. 456
    Alternaria spot.. 464
2. Spots mostly smaller than the above, deep seated and more definitely cupped. Usually darker in color. Beginning in injuries to the skin, and starting in the orchard in damp weather. Spread of spot mostly greater in the inner than in the outer part of rind. Especially on lemons occurring in California and Italy—
    Black pit.. 443
3. Similar to the last, at first yellowish brown, a cinnamon-pink brown; later dark brown to blackish brown. In South Africa—
    Bacterial spot of South Africa.................................. 450
4. Spots developing mostly in storage and on lemon fruits. At first in the form of sunken pits without discoloration of the surface. Caused by collapse of a portion of the inner rind without apparent external injury—
    Petcca.. 441
5. Light-colored to brown sunken spots in fruit that has been in cold storage—
    Cold-storage spot or "pox" (late stage)........................ 474
6. Corky spots, occasionally depressed but usually raised, with cleavage between the affected and sound tissue; usually with distortion of fruit while growing; on Mexican or West Indian limes (see also IV-*C*)—
    Lime Anthracnose.. 461
7. Dead circular scabby spot, preceded by a dark chocolate-colored felty mass on the surface of the fruit, sometimes involving the entire thickness of the rind. Fruit sometimes deformed; Egypt—
    Chocolate spot.. 276
8. Depressed furrows extending in various directions where the normal rind has sunken—
    Creasing.. 520

B. Typically shallow, slightly sunken spots involving only a small part of the thickness of the rind:

1. Spots variable in size, light brown to dark brown. Extending inward to a maximum of one-fourth the thickness of the rind. Occurring without visible abrasion, mostly on smooth-skinned navel oranges, ten to fifteen days after picking—
    Brown spot of navel orange.................................. 472
2. Spots or stains variable in size and shape involving a small or greater part of the surface of lemon fruits in storage. At first a reddish

PAGE

blush; then a cinnamon brown stain, resulting later in firm, tough areas involving the layer containing the oil glands, becoming reddish brown, chestnut brown to dark brown—
    Adustiosis or red blotch 440

3. Spots showing tissues between the oil glands slightly sunken, with oil glands standing out prominently like papillæ. Green or brown on stored fruit, reddish brown or brown on fruit on tree—
    Oleocellosis (oil spot and green spot) 466
4. Similar to the last following frost or hail—
    Frost marks 429
    Hail marks 466
    Scalding 523
5. Small green pits or depressions on lemon or mandarin fruits. Depressions becoming reddish when fruit thoroughly matures—
    Septoria spot 477
6. Small, reddish brown to black, more or less circular spots about $\frac{1}{12}$ to $\frac{1}{3}$ inch in diameter. Somewhat depressed in the center with black pycnidia, and with raised margins, not deep in the rind. China and Australia—
    Black spot 479
7. Sunken spots variable in shape and color—
    Miscellaneous fruit spots 520

IV. Not typically sunken spots (if so very slightly) on or within the surface layers or raised above the surrounding tissues, stains, markings, dots, pustules or scab-like effects:

A. Not prominently raised above the surface nor prominently sunken; resulting from changes in the surface cells of the rind:

1. Irregular areas of glossy resinous-like stain, starting on fruit while enlarging on the tree; chestnut to soft brown in color, often accompanied by splitting and by gum near the core—
    Exanthema 501
2. Smooth to slightly roughened effects involving part or all of the exterior; russet brown on oranges, grayish silver on lemons—
    Rust-mite markings 503
3. Like the last with entire skin thick, leathery and scurfy, mostly on grapefruit—
    Buckskin 503
4. Surface stains or markings reddish brown to reddish green, causing streaks or bands on the smooth surface—
    Tear staining 505
5. Much like preceding on lemons in storage, but more sunken in later stages (III *B*). Beginning stage of—
    Red blotch 440
6. Irregular areas of thin, minute, silvery or grayish scales in the form of scurf on the surface—
    Thrips injury 506
    Wind chafing 509
7. Surface layers of gray to brown-colored flat crusts formed from death of surface layers with sound tissue beneath—
    Wind rubbing 509
    Fumigation injury 513
    Spray burns 515

PAGE

B. Superficial spots or markings which may be washed or easily rubbed off from the surface:

1. Small black dots scattered over the surface—
   Flyspeck fungus 500
2. Black, sooty, dry mold-like condition usually obscuring the surface—
   Sooty mold 253
3. Fainter less prominent blotches only partially obscuring the surface—
   Smoky fungus 500
4. Small raised pustules spherical or elongated, of various colors, easily scraped off without disturbing the rind—
   Scale insects 263
   Entomogenous fungi 266

C. Raised above the surface in the form of rough or smooth pustules and scab-like prominences, not readily rubbed off. Arising from changes or hypertrophies in the outer cells of the rind, and fixed to it:

1. Affected areas variable, usually spongy or corky scab-like elevations beginning on young fruit, tan colored to brown. Frequently sunken as fruit develops—
   Cancrosis or Citrus canker 482
2. Similar to the last on oranges under certain weather conditions in California when trees are fumigated while fruit is half grown—
   One form of fumigation spot 514
3. Affected areas cream colored to brownish and even pinkish, more irregular and usually more elevated than the last; scabby elevations frequently causing much distortion of young fruits while developing—
   Verrucosis or scab 485
4. Corky, scab-like spots, usually raised, occasionally depressed, with cleavage between the affected and sound tissue; with distortion of fruit (III-*A*); on Mexican or West Indian limes—
   Lime anthracnose 461
5. Pustules small, $\frac{1}{50}$ to $\frac{1}{25}$ inch (0.5 to 1 millimeter) in diameter or larger. Nearly circular in outline. Smooth on top, wax-like, breaking around the edges. Yellowish brown, dark brown to blackish brown. Often occurring in lines or parts of circles—
   Melanose 496
6. Producing grayish-white, compact, cork-like formations on the surface of mandarin fruits in southern Russia—
   Exobasidium 503
7. Reddish-brown to black spots $\frac{1}{2}$ to $\frac{1}{3}$ inch in diameter with raised margins and depressed in the center (see also III-*B*). In Australia and China—
   Black spot 479
8. Continuous scab-like areas sometimes raised above the surface by growth of new tissues underneath:
   a. Fine gray scurf—
      Thrips injury 506
      Wind injury 509
   b. Rougher coarser scurf or scabs—
      Fumigation injury 513
      Rubbings, etc. 509

CHAPTER XVI

FRUIT ROTS

COMMON GREEN OR OLIVE-GREEN MOLD

This mold is probably the most common form of soft decay in Citrus fruits. It is world wide in distribution—in orchards, in packing houses and on the markets. The fungus *Penicillium digitatum* Sacc. depends primarily upon injuries to the skin of the fruit. The spore masses, as they develop upon the surface, are olive green in color and powdery. This decay is frequently found associated with blue-contact mold. Both together are commonly known under the general term of "blue molds."[1] When the particular one due to *P. digitatum* is being specified, it should be known as common green or olive-green mold.

Symptoms.—The common green mold due to *P. digitatum* begins almost invariably through some injury to the skin. A water-soaked, soft area appears, easily punctured by the pressure of the finger. This enlarges rapidly and a white mycelium appears on the surface, followed by the development of olive-green powdery spore masses which form a dust cloud when disturbed. At first, the green areas form at the center and are surrounded by a band of white mycelium (Fig. 112A, B). The main diagnostic characteristics are: (1) the wide white margin ahead of the green area while the soft areas are enlarging; (2) the white area of mycelium usually pasty and wrinkled; and (3) the wrapper adhering readily to the fruit and the green spore masses confined to the surface of the fruit. In these three respects, it differs from the blue-contact mold described later, in which the mycelium has a more powdery, softer appearance, is not so wrinkled, does not adhere readily to the wrapper, and in which the spore masses are not confined to the surface.[2]

The entire fruit with the green mold soon becomes involved and is finally a soft shrunken mass covered with a layer of olive-green spores. If the humidity is low or moderate, the whole fruit will shrink to a wrinkled dry mummy, but if the humidity is high, other molds and bacteria enter, and the fruit frequently flattens into a decomposing softer mass. The color of the spore masses varies somewhat with age, but is represented by Ridgway's (1912) shades of pea green, greenish olive and olive green.

---

[1] A form of Penicillium decay has also been referred to as blister rot by Winston, Fulton and Bowman (1923).

[2] For these distinctions, we are indebted to the observations of W. A. Barger and A. E. Nelson.

In general, there is no blue color present unless this fungus is mixed with the blue-contact mold, as is frequently the case. It may, in rare cases, show a bluish-green color. The common green mold frequently starts after the blue-contact mold has well started, producing a mixture with the green color soon predominating but with a considerable amount of a bulish color in the final mass.

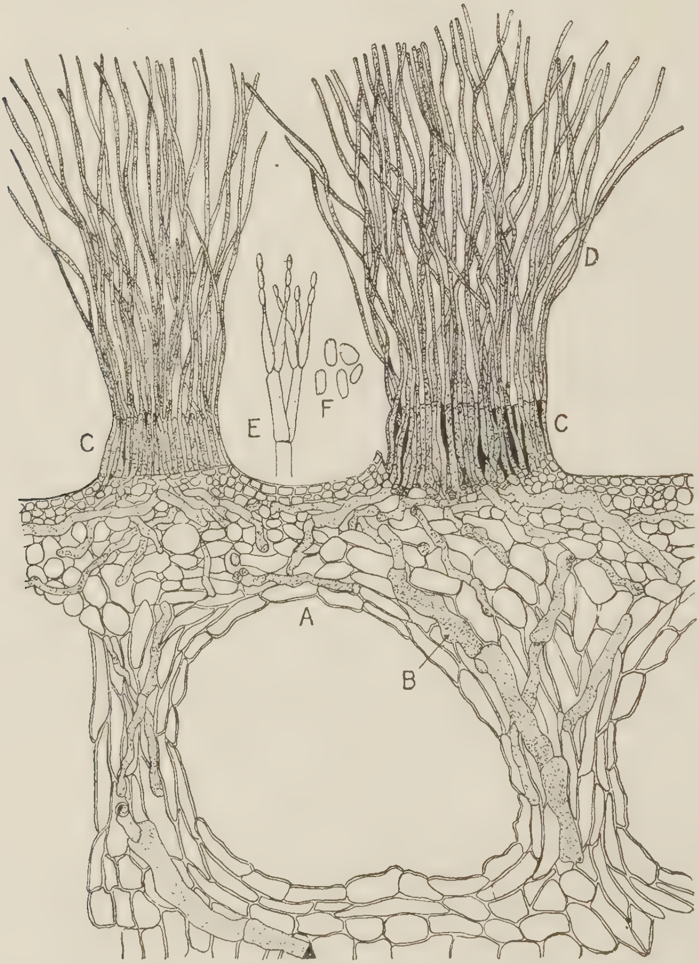

FIG. 110.—*Penicillium digitatum.* Enlarged section of the decaying orange rind; A, an oil vesicle; B, filaments of the fungus, ramifying within the tissues; C, pustules, on the surface from which have grown out clusters of aerial hyphae (D); the sporophores and spores (E) are borne on the ends of these filaments; F, spores more enlarged. A, B, C, D magnified about 90; E about 180 and F about 375 diameters. (*After R. E. Smith* (1897).)

The fungus penetrates and breaks down the rind. It does not appear at first (in lemons at least) to extend deeply into the fleshy portion or pulp but gives it a bitter, disagreeable flavor. When the surface fungus first appears, it is seen under a microscope as tufts of white mycelium extending out from the surface (Fig. 110), and within the rind are found hyphæ penetrating and breaking down the cells (Smith 1897).

Causal Agent.—The causal agent is a very common mold fungus, *Penicillium digitatum* Sacc., which is world wide in its distribution on Citrus fruits. An injury or abrasion on the surface of the fruit is necessary before this fungus can begin to produce decay. Such injuries are furnished in many ways in the usual operations of growing and marketing the fruit.

The characteristics of the fungus have been clearly described by Thom (1910) as follows:

> Colonies on sugar gelatin and potato or bean agar grayish olive, irregularly shaped from the unequal growth and branching of rather few hyphæ, aerial portion consisting only of very short conidiophores and conidia. Reverse of colony commonly shows brown to black colors. Conidiophores rising directly from the substratum, 30 to 100 by 4 to 5μ, usually very short. Conidial fructification, a few tangled conidial chains up to 160μ in length, borne upon conidiiferous cells 13 to 16 by 3 to 4μ. Conidia cylindrical to almost globose, 4 to 7 by 6 to 8μ (at times 6 by 10μ), often uneven in size and shape in the same chain (Fig. 111). Colonies do not liquefy sugar gelatin except at times partially in cultures three weeks old or more Litmus reaction acid. Grows readily on organic media, but shows a very pronounced affinity for such media with high percentages of sugar, in which it produces a strong odor. Refused to grow in synthetic media containing nitrogen as sodium nitrate.

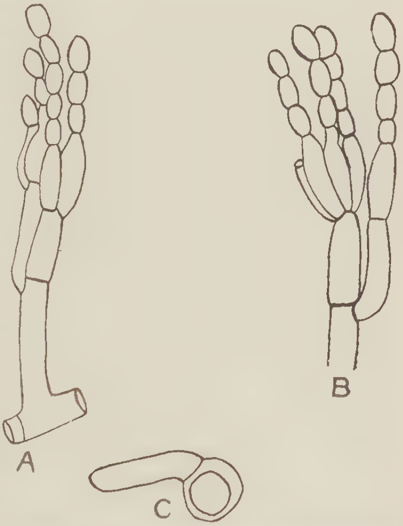

FIG. 111.—*Penicillium digitatum* Sacc.: A, B, conidiophores and chains of spores; C, germination of a conidial spore. ×550. (*After Thom* (1910).)

This fungus may be found everywhere on fruits in the markets and may be distinguished from the blue mold by its pea-green, greenish-olive to olive-green color.[1] The spores of this fungus average a little larger and tend to be more elongated than those of the *P. italicum*.

White-mold Mutation.—A white strain or mutation of Penicillium, closely resembling the common green-mold fungus, *P. digitatum*, but with white chalky-colored spore masses, has been frequently met in California. Dr. Thom examined this strain in cultures and finds it resembles *P. digitatum*. Its effect in rotting fruits is nearly the same as the other. In the strains experimented with, it appeared to rot the fruit a little faster even than the common green strain. The fruit becomes a wrinkled mummy with a coat of white instead of green-colored spore masses.

---

[1] Another species of green mold, *Penicillium stoloniferum* Thom, is sometimes found attacking oranges and lemons partially rotted by other fungi (Camp 1923). Its spore masses are usually green or yellowish green, becoming gray green with age (Thom 1910). The spores are smaller than those of *P. digitatum*.

Contributing Conditions.—As has been previously stated, this common green-mold decay, as well as the blue-contact decay, is closely related to injuries or abrasion to the skin of the fruit. The conditions that make for increased green- and blue-mold decay are so aptly described by Hobson (1922) that the following extract is quoted:

> The great number of oranges seen in London almost daily that have been cut and packed with long stems is proof positive that many growers are not fully alive to the amount of mechanical injury caused by even one fruit with a long stem in the picking bag, the lug box, the sizer and the finished case. The fact that the slightest abrasion to the skin of an orange at once renders it an easy prey to attack by the Citrus exporters' greatest enemy—"mould"—is one so old, well established and universally accepted that it seems hardly credible that a warning in regard to care in handling should, at this stage, be necessary, but since such sights as:
>
> 1. Fruit intended for export piled up in large heaps on the ground and left absolutely exposed to the elements for several days;
> 2. Fruit pulled from the tree;
> 3. Fruit cut with long stems;
> 4. Lug boxes and export cases bristling with splinters;
> 5. Native pickers with any kind of clippers, no gloves and no efficient supervision;
> 6. Faulty sizers carelessly worked;
> 7. Lug boxes containing fruit banged about on springless vehicles;
> 8. Faulty packs and no efficient supervision in packing house;
> 9. Packed cases handled like footballs, and stacked "bottom up," "bulge up," and trampled upon;
>
> are so very frequently seen, a further word of warning becomes an absolute necessity.

Apart from the mere mechanical injury of the tissue, secondary effects result from the oil or the juice liberated or from oxidation or other chemical reactions following injury. Citrus oil liberated from the glands has a severe effect upon the surface cells, causing them to break down and allowing the entrance of mold fungi. If punctures or injuries are such as to allow juice to come in contact with the surface or to run over other fruits, an ideal medium is furnished for the germination and entrance of the mold fungi. Juice of lemon fruits was allowed to fall upon a lot of other sound lemons. The experiment showed that a large percentage of these fruits that were subjected to drops of juice, when set aside, were later affected with blue and green mold, while other fruit not so treated remained sound. Other contributing conditions, such as age and weakness of the fruit, humidity of the atmosphere and temperature, are also important.

Control.—The principle that requires emphasis above all else in the control of common green mold is careful handling of the fruit during all operations of its growing and marketing to avoid injuries and abrasions. Injuries and abrasions may start either in the orchard or during the handling of the fruit in picking, hauling, washing, sizing, grading, packing, shipping and marketing. A treatment of the fruit that should not be substituted for careful handling, but which is being used as a supplement or further aid to the prevention of this mold, is soaking the fruit in a borax solution. The details of control for both common green and blue mold may be found on page 360 following the discussion of the blue-contact decay.

BLUE-CONTACT MOLD

This form of soft decay, due to the fungus *Penicillium italicum* Wehmer, is somewhat similar to the common green mold and is also a common form of rot in Citrus fruits. For the most part it is caused also by injuries. It has a greater tendency, however, than the common green mold to spread from one fruit to the next by contact, apparently through the uninjured skin and quite often through the cut stem end. For this reason it is designated as the "blue-contact" mold. In early stages, it is frequently known as "pinhole" decay.

Symptoms.—Except when this rot starts by contact with another fruit, it usually begins at an injury or abrasion, as does the other form previously described. A water-soaked, soft area appears, which is easily punctured by pressure of the finger. In most cases, the initial spots of blue mold enlarge more slowly than those of the common green mold. These initial spots when small are often known on the markets as "pinhole" decay. As the spots enlarge, a white growth (mycelium) develops on the surface followed by the development of the blue spore masses. The blue color forms and spreads with the enlarging area, leaving only a very narrow white fringe (Fig. 112C, D). There is also a halo of water-soaked, faded tissue between the fringe of white mycelium and the sound surface tissue. This is usually more pronounced in this blue-contact than in the other mold. The white mycelium has a powdery appearance and seems more deeply seated than in the common green mold. After the rot has well started, the blue spore masses usually develop inside the fruit at the core or inner spongy part of the rind as well as on the surface. In California oranges, these appear, on the average, after the decay has involved about one-fourth to one-third of the surface of the fruit. The colors of the spores are slightly varying shades of blue, represented by Ridgway's (1912) light glaucous blue, glaucous blue, lumiére blue or bremen blue. The fruit is finally covered with a mass of the blue spores, which may change with age to a brownish-olive color. The inner tissue of the fruit appears to be somewhat more completely broken down by blue-contact mold than by the olive green, although there is not much difference. Frequently, both the blue and green are associated, and it is usual to find the common green mold appearing after the blue has first begun to break down the fruit. Where both are present on the same fruit, the green color of *P. digitatum* tends to become dominant.

POINTS OF DIFFERENCE BETWEEN COMMON GREEN AND BLUE-CONTACT MOLD

COMMON GREEN, *P. digitatum*	BLUE-CONTACT, *P. italicum*
Spores	
Olive green forming on surface only	Blue forming on the surface and also inside of the fruit
Mycelium	
Pasty, wrinkled, showing much in advance of the spores	Powdery, not showing much in advance of the spores
Margin of Decay	
An indefinite band with margin not well marked ahead of mycelium on the surface	Definite, with a soft water-soaked band just ahead of the mycelium on the surface
Wrapped Fruit	
Wrapper closely adhering to the rotting fruit	Wrapper not readily adhering to the rotting fruit

Causal Agent.—The agency in the soft breakdown of the tissue is a fungus, *Penicillium italicum.* This according to Thom (1910) is the same as that discussed under the name of *P. glaucum* by R. E. Smith (1907), Powell (1908) and others. An injury or abrasion is usually necessary for the fungus to start in breaking down the tissue, except when a fruit is in contact with one already rotted or where a fruit is weak and the fungus begins its growth at the stem end.

This fungus is clearly described in detail by Thom (1910) as follows:

> *Penicillium italicum* Wehmer. Colonies on plain gelatin and potato or bean agar bluish green, becoming gray green when old (bright bluish green on cane-sugar media and Citrus fruits), broadly spreading, aerial portion composed at the broad margin almost entirely of conidiophores, but becoming slightly floccose in the center. Reverse of colonies dark brownish, often almost black in media containing sugar. Conidiophores from short (100μ) to very long (600μ), averaging perhaps 250μ, arising either directly from substratum or as branches of aerial hyphæ (Fig. 113). Conidial fructifications up to 300μ or more in length, consisting usually of a main branch and one lateral branch, each producing a whorl of branchlets bearing crowded verticels of conidiiferous cells, 12 to 14 by 3μ. Conidia breaking off in masses in handling old cultures, which rise in clouds when shaken. Conidia 2 to 3 by 3 to 5μ cylindrical to elliptical or slightly ovate, clear green by transmitted light, very variable in size but

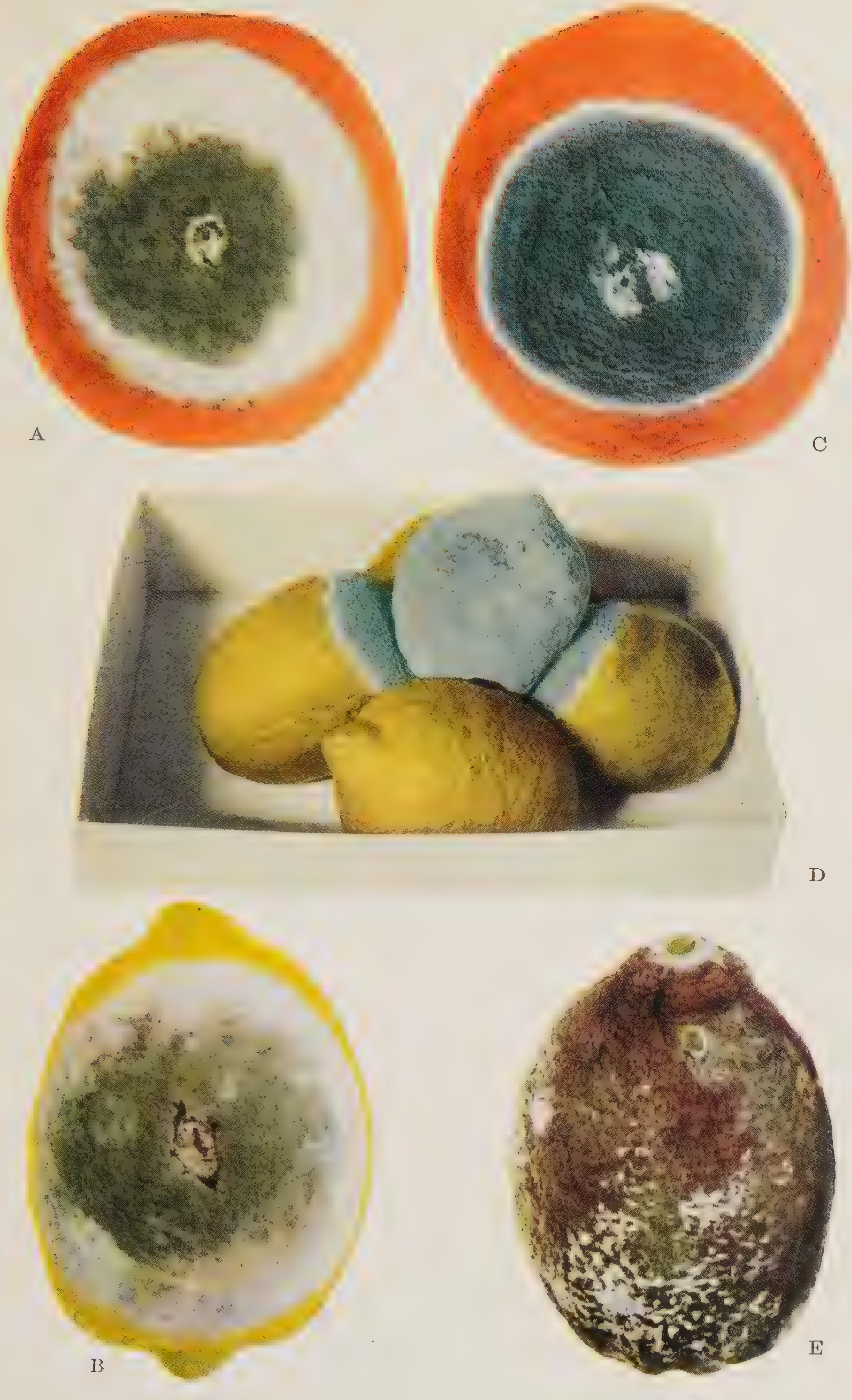

FIG. 112.—Common green mold, blue-contact mold and Trichoderma rot. A, Common green or olive-green mold due to *Penicillium digitatum*, on orange. B, Common green mold on lemon. C, Blue-contact mold due to *Penicillium italicum*, on orange. D, Blue contact mold on lemons spreading by contact. E, Trichoderma rot due to *Trichoderma lignorum*, showing green spore masses on lemon (see also Fig. 136E and F).

(*Facing page* 358)

usually within the limits given. Masses of spores continue to increase from two to three weeks. Petri-dish colonies partially and slowly liquefy gelatin (twelve to twenty days).

This fungus is fairly common on decaying Citrus fruits as a glaucous-blue to lumiére-blue mold and almost always has with it the common green-mold fungus, *P. digitatum.*

Contributing Conditions.—This blue-contact mold like the common green results for the most part from abrasions or injuries to the fruit. It has, however, ability to pass from one fruit to another by contact in a box, especially on weak fruit, and for this reason is considered more serious than the common green. It may also, on fruit weakened by frost or on fruit held for a long time in cold storage, enter through the cut stem or "button" and break down the fruit as an end rot. As in the common green mold, age and weakness of the fruit, humidity of the atmosphere and temperature are also contributing factors for the occurrence of the blue contact mold.

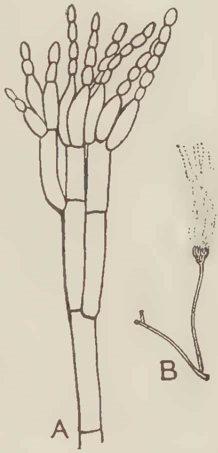

Fig. 113.—*Penicillium italicum* Wehmer: A, conidiophore and conidial chains ×550; B, sketch of conidial fructification ×85. (*After Thom* (1910).)

History of Green- and Blue-mold Control.—In the earlier days of the orange and lemon industry in California, heavy losses were experienced from excessive decay of fruit in transit and on the markets. The first noteworthy investigation of the factors involved in this type of decay were those of Powell (1908) and his coworkers, in which he demonstrated by numerous experiments that a large amount of decay came from avoidable injuries to the fruit. The adoption by the California growers of methods for prevention of this injury resulted in cutting down this excessive decay. Later, an investigation by Stubenrauch, Ramsey *et al.* (1914) and Ramsey (1915) under Florida conditions demonstrated the same facts for that section and also brought out much additional information as to the detailed relation of orchard, packing house and shipping conditions to this type of decay. More recently, under South African conditions, the same and other additional factors have been demonstrated in connection with decay in Citrus fruits (Evans *et al.* 1921); Thompson, Putterill and Hobson 1922). In Australia, Adams (1923) has worked on the storage of Citrus fruits. Many other publications on the subject might be cited but reference to them will be found in the bibliography.

Recently, the use of a solution of borax as a supplementary treatment has been tried out and appears to be promising in cutting down a large percentage of blue- and green-mold decay. A number of experiments were carried out by Fulton and Bowman (1924). After testing out a large number of chemicals, they suggested the use of borax. Further suggestions for its use have been published by Fulton and Winston (1924), by Barger and Hawkins (1925) and by Barger (1925). In California, the borax soaps in the process of washing fruit have been used for a number of years.

Control of Blue-contact and Common Green Mold.—Since the control methods are practically the same for both the blue-contact and the common green mold, they will be included here under one heading. The principle requiring emphasis above all else is careful handling to avoid injuries during all operations. A supplementary method of borax treatment has recently been tested out but cannot be expected to be a substitute for careful handling.

Careful Handling.—The following has been extracted largely from the excellent discussion of the subject by Ramsey (1915, 1921). The injuries may originate in numerous ways. The terms which may be mentioned in this connection are clipper cutting, long stems, pulled fruit, thorn punctures, ladder bruises, dropping and throwing the fruit into the sack, scratching the fruit with finger nails, squeezing the fruit against the ladder, dropping it too far into field boxes, injuring with sand, gravel, splinters, protruding nails left in field boxes, jolting over rough roads on springless wagons, bruising or dropping during cleaning, drying, grading, sizing and packing, improper loading, etc.

The suggestions for prevention of such injuries may be listed as follows:

1. Gloves provided for pickers, to avoid finger-nail scratches.
2. Suitable clippers, properly sharpened and adjusted with dull or rounded points to avoid cutting the skin or leaving ragged fragments in clipping.
3. Care that fruit is carefully placed, not dropped, thrown nor "shot" into the picking sack.
4. Precaution against pressing the fruit between the body and the ladder or branches while picking, in order to avoid bruises therefrom.
5. Care in placing or moving ladders to avoid bruising or scratching the fruit.
6. Suitable picking sacks that may be opened at the bottom after lowering in the box, so that fruit may roll gently, not drop, into the box.
7. Field boxes in repair and free from protruding nails, loose knots, splinters, sharp points, gravel or twigs.
8. Boxes with bottom entirely boarded to avoid injury from gravel, weeds or cover-crop stems, etc.
9. Avoidance of heaping fruit in boxes to prevent injury when loading.
10. Careful handling of boxes in loading and unloading.
11. Wagons or trucks with good springs.

12. Boxes tied securely if they are to go over rough roads, to avoid shifting and jostling about.

13. A reliable foreman over each picking crew to make frequent inspections of each picker's work for clipper cuts, long stems, injuries and inperfections, and to inspect clippers and see that they are in perfect condition.

14. Frequent inspection of machinery in packing house to avoid protruding nails, splinters, rough corners, etc.

15. Avoidance of sharp turns, angles, gravity runs, and drops in the packing house.

16. Establishing good sanitation in the packing house and avoiding accumulation of rubbish, decaying fruit, etc.

17. Avoidance of careless emptying of the fruit at the washer.

18. Picking out fruit having worm holes and decay, before these go in to the washer.

19. Avoidance of injuries from poorly constructed washers, worn and defective brushes.

20. Avoidance of dirty or contaminated water in washing.

21. Precaution against burning the fruit, if hot water is to be used. Fruit varies as to the maximum temperature that may be used without injury. Lemons usually stand from 115 to 120°F. for several minutes. At certain seasons of the year, it becomes necessary to hold them twenty-four to forty-eight hours after picking and before washing, to avoid injury from hot water.

22. Drying of oranges as rapidly as possible after washing. Since lemons are usually not packed at once, rapid drying is not practiced. This is to avoid shrinkage.

23. Gloves in handling fruit, in grading and packing to avoid injuries from finger nails.

24. Extra graders if necessary to eliminate worm-injured or defective fruit.

25. Packing bins padded and free from dry twigs and trash; and avoidance of dragging the fruit around in the bins or tossing them from place to place.

26. Fruit packed firmly and tightly in the box to avoid slackness in transit and on arrival.

27. Tops pressed down and nailed with care to avoid tearing or breaking the skin of the fruit on the top layer.

28. Most Citrus fruits except lemons and perhaps limes shipped as soon as possible after removal from the trees, to avoid increased decay.

29. Boxes loaded securely in the cars to avoid damage and injury in transit.

Borax Treatment.—Although the borax treatment is still somewhat in an experimental stage, it has had a considerable number of tests under commercial conditions. As a result of experiments in Florida, Fulton and Winston (1924) suggest the use of a 5 per cent solution of borax in hot water for five minutes. In California, tests by Barger and Hawkins (1925) showed control of the common green mold, *Penicillium digitatum*, by either 2.5 per cent boric acid or borax, and other tests on a commercial scale (Barger 1925) showed marked control with borax. Their data indicate that with borax or boric acid hot water is not essential for control of the common green mold, *P. digitatum*, but that there is little or slight retarding of the blue contact, *P. italicum*, at less than 125°F.

For the borax treatment, an additional tank is necessary to be placed so that the fruit goes through it after it has been washed in the regular way. This will help to keep the borax clean and save renewal costs. This additional tank may be constructed so as to require about four to six minutes for the fruit to pass through it. It may be long and broad and comparatively shallow. A final light spray of water may be used to remove excess of borax.

It cannot be emphasized too strongly that this borax treatment cannot be expected and should in no way be a substitute for careful handling to avoid injuries. Borax will prevent only a part of the decay. Injuries to the fruit are undesirable under any conditions, and bad injuries will result in dry sunken spots.

There are certain proprietary processes in commercial operation at present in California, which usually consist (1) in the use of some substance in the wash water or soaking tank for the purpose of preventing decay and (2) the employment of a waxy or oily coating to prevent normal shrinkage and the preservation of a fresh appearance. It should be pointed out that when waxes or oils are used, the gas exchanges in the normal respiration processes of the fruit are likely to be considerably altered. It is not definitely known how much respiration may be altered without impairment of Citrus fruit. In experiments with waxes and oils on apples, Magness and Diehl (1924) found that too heavy a coating resulted in anaerobic respiration and the development of disagreeable flavors.

Without either condemning or recommending, as yet, any of these processes aiming to prevent decay, shrinkage and deterioration, it should be pointed out that many trials under varying conditions with entirely comparable untreated controls for comparison should be made before definite conclusions are finally reached in regard to them.

PINK MOLD

A pink-colored mold due to a fungus resembling *Pencillium roseum*[1] is frequently in evidence on lemons subjected to high humidity in the

[1] According to Charles Thom, to whom we are indebted for examination of this fungus found on Citrus, it belongs to the group of pink forms related to *P. roseum* of his publication (1910).

packing house or on the way to market (Fawcett 1925*a*). It has not been noted on oranges. We have found orange fruit more resistant than lemons to inoculation. So far as known, this mold has not been previously reported, though we have seen it on California lemons for a number of years. It is usually, but not always, accompanied by the common green or blue-contact mold previously described, and is probably for the most part secondary to them.[1]

In some cases on old weak lemon fruits, it appears to produce a decay whose final effects are much the same as the other two molds, except that, instead of the blue or green color there is a surface mass of spores usually salmon buff or buff pink in color, not so powdery, however, as in case of the green and blue molds. In mixtures with other fungi, it may produce coral-red, vandyke-red, brick-red and even dragon-blood-red colors. Many cars of lemons, on arrival from California during the summer and fall months of 1924, showed this pink-colored fungus on fruits that appeared also to have the blue or green mold. It also appeared to be common in basements of lemon packing houses in California with fairly high humidity.

Characteristics of the Fungus.—The fungus to which this Citrus strain is closely related has been carefully described by Thom (1912) as follows:

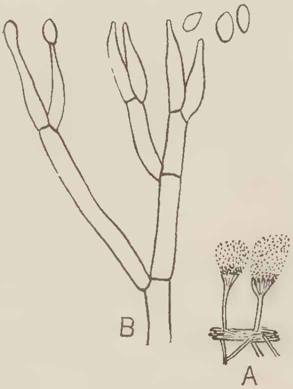

FIG. 114.—*Penicillium roseum* Lk.: A, sketch of ripe fructification indicating agglutination of conidia into slimy masses; B, conidial fructification with conidiiferous cells and conidial spores ×550. (*After Thom* (1910).)

Penicillium roseum Link. Colonies on milk-sugar gelatin or potato agar white to pink or salmon in fruiting areas, loose floccose with simple hyphæ and ropes of hyphæ, producing dense irregular pinkish masses of sclerotia up to 1 millimeter or more in diameter in old culture. Conidiophores borne as perpendicular branches of aerial hyphæ or ropes of hyphæ, 45 to 125μ. Conidial fructification up to 140μ in length, once or twice irregularly alternately or verticillately branched, with conidiferous cells varying from 12 by 2 to 3μ in the verticils of 5 or less to 17 by 2.3μ when solitary, bearing conidia which become aggregated into gelatinous balls or masses (Fig. 114). Conidia colorless (pink or rosy in mass), elliptical, 5 to 7 by 3 to 5μ, slightly apiculate, smooth, appearing delicately granular within. (It differs from most common Penicillium species in developing a mucilaginous mass enveloping the spore clusters. Thom (1910) points out that this feature (if sufficient for separation) would give it the generic name of *Gliocladium*.)

---

[1] A yellowish-green Penicillium also accompanies it and is now being studied. When growing with *P. roseum* in cultures the coral-red to brick-red color seen on decaying fruits was produced by the combined action of the two species, but not by either of them alone.

This fungus is common in the Citrus orchards of California, frequently found on dead or weakened tissue on the bark as a pink-colored mold associated with gummosis-inducing organisms. It is thought to be capable of inducing small amounts of gum on wounded lemon tree trunks under certain conditions (Fawcett 1923*b*).

TRICHODERMA ROT

A minor decay which has probably been mistaken in the past for common green mold (since the final color on the surface is green and powdery) is that due to a fungus, *Trichoderma lignorum* (Tode).[1] This decay has so far been met with principally in the lemon-packing houses, and in fruit in storage in the United States eastern markets during the summer months (Fawcett 1925*a*). The same fungus has been isolated from dead or dying orange roots injured by water logging and from date palm roots. The same or related species occurs on rotten wood and in the soil. It breaks down old mature fruit more readily than fresh mature fruit. Inoculation experiments have shown that, like blue and green mold, it is capable of breaking down both oranges and lemons when these are injured and the spores inserted. It produces a much firmer rot and is usually much slower in development than the blue and green Penicilliums.

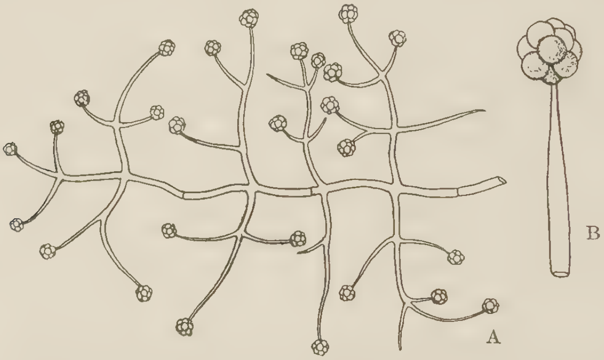

Fig. 115.—*Trichoderma lignorum:* A, spore-bearing hyphae (conidiophores) and spores (conidia) magnified 350 diameters; B, single branch bearing a cluster of spores magnified about 1500 diameters. (*After Lindau e. Harz.*)

Symptoms.—The Trichoderma decay begins as a firm to somewhat pliable, leathery, surface rot, pinkish brown to cocoa brown in color, without at first perceptibly breaking down the interior. Later, it may advance into the core and spongy part of rind beyond the discoloration on the surface and become rather pliable and leathery and frequently soft. The color on lemon fruits is pinkish brown to cocoa brown (Ridgway's shades of cameo brown, vorona brown or cocoa brown) (Figs. 112E, 136). After a long time in moist atmosphere, surface mycelium appears in whitish clumps or cushions, at first scattered or later forming a nearly continuous mass, with development of spore masses of Ridgway's meadow green, antique green, Russian green or stone green (Fig. 112E). Oranges are affected by inoculation in a similar manner.

---

[1] This fungus was examined by Dr. C. L. Shear, who states that it appears to agree with the common *T. lignorum*.

Characteristics of the fungus: The fungus *Trichoderma lignorum* (Tode) is a common inhabitant of decaying wood or roots, and is generally considered to be almost wholly saprophytic in nature. The mycelium is usually white but may become yellowish or light green. It grows close to the surface of most culture media and is much septate. The spore-bearing hyphæ are branched in a manner shown in Fig. 115. The final branches (Fig. 115B) bear at their tips ten to twenty spherical spores 2.5 to 3 μ in diameter packed close together. With age the spores are formed in continuous powdery masses with shades of color as indicated above. This fungus is supposed to be the conidial form of the ascomycetous fungus called *Hypocrea rufa.*

Control.—Since the Trichoderma rot is probably related to injuries and other conditions similar to those causing green and blue Penicillium molds, the means used to control these latter forms of decay would also prevent any large amount of Trichoderma rot. It has not, however, so far attracted attention as a major decay of Citrus fruits.

ASPERGILLUS ROT

This is a minor form of soft decay due to the very common fungus, *Aspergillus niger* Van Tiegh. The fungus does not appear to be capable of rotting Citrus fruit rapidly except at fairly high temperatures or in storage rooms where the temperature is unusually high.

Symptoms.—Aspergillus rot starts as a light-colored, very soft, easily punctured spot somewhat similar to the beginning spots of the common green and blue-contact mold. On oranges at about 75°F., the spots become pale orange, yellow or primrose yellow, and the tissue tends to become wrinkled. As the rot develops further, there is a sinking of the decayed area with the appearance of the mycelium and the fruiting bodies of the fungus. This forms a black powdery layer over the surface of the rotted area. This black powdery layer contains numerous spores of the fungus which are carried about by currents of air in the same way as the Penicillium spores are carried. On lemons, depressed pits $\frac{1}{12}$ to $\frac{1}{8}$ inch in diameter are at first formed over the surface. Formerly, when rather high temperatures were used in the sweating of lemons and oranges to change the color rapidly, this rot was found troublesome in the sweat rooms. At high temperatures, the buttons became black and the rot began to progess from the stem end (Fig. 116).

Causal Agent.—*Aspergillus niger*[1] is a very common fungus with powdery air-borne spores, black in mass. Spherical heads are formed made up of chains of conidia radiating from the swollen knob of the conidiophore (Fig. 117). "The head may be 100 to 400μ in diameter. As designated by Thom and Currie (1916), *A. niger* has both primary and secondary sterigmata, the primary sterigmata being 20 to 30μ in length. The conidia are usually about 2.5 to 4μ in diameter." The conidial walls are rough with irregular but usually oblong or bar-like masses of coloring matter.

---

[1] We are indebted to Dr. Charles Thom for identification of this fungus from Citrus fruits.

Control.—This rot is usually not considered at all serious except when temperatures become unusually high. Keeping the temperatures as low as possible and using the same precautions as for preventing common green and blue-contact mold decay would probably successfully control this mold

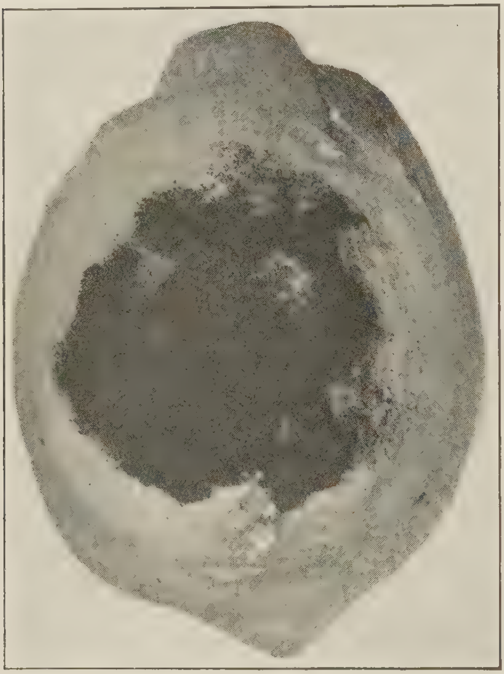

Fig. 116.—Soft rot due to *Aspergillus niger* on lemon fruit.

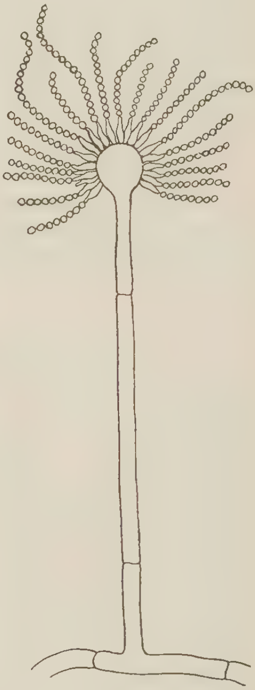

Fig. 117.—Spore-bearing hypha (conidiophore) showing sterigmata and chains of spores on its swollen end. (*After Phillips, Smith and Smith* (1925).)

RHIZOPUS ROT

Species of Rhizopus are capable of producing a soft rot of Citrus fruits under certain conditions. This type of rot has been mentioned by Earle and Rogers (1915) as occurring in Cuba on grapefruits. It is usually of minor importance. It has seldom been noted on California Citrus fruits. Like the blue molds, it starts at injuries to the rind. A 5 to 6 per cent loss of fruit is mentioned as occurring in Cuba from this decay. Rhizopus is mentioned as a rot of minor importance by Stevenson (1918) in Porto Rico. That a large number of species of Rhizopus are capable of producing decay in wounded fruits of grapefruit, orange and lemon was shown by Harter and Weimer (1922). The following species of Rhizopus when placed in punctures produced decay: *Rhizopus chinensis, R. oryzae, R. maydis, R. tritici, R. delemar, R. nodosus, R. artocarpi, R. reflexus, R. microsporus* and *R. nigricans.*

Symptoms.—The decay begins in a similar manner to that of Aspergillus rot, the tissue is softened and easily punctured and later becomes covered by a fluffy mass of mycelium with dark heads of spores which gives it a gray to black color. The mycelium is usually more conspicuous in moist air than is that of Aspergillus. Precautions against injury as in green and blue mold are the preventive measures suggested.

ROLF'S SCLEROTIUM ROT

A minor form of decay due to *Sclerotium rolfsii* Sacc. has been reported in Cuba (Earle and Rogers 1915), usually on fruit that is touching the ground. The same fungus has also been reported on Citrus seedlings in Florida, Porto Rico (Stevenson 1918) and Alabama (Wolf 1916*b*). The fungus is widely disributed in many parts of the world, especially the semitropical regions, on a large number of different hosts. Taubenhaus (1919) records thirty-two host plants in addition to Citrus.

Symptoms.—The following characteristics were observed in orange and lemon fruits inoculated with pure cultures of the fungus:[1] The rapidity of rotting was about the same on both the orange and lemon fruits. In one week at 65 to 75°F. the areas were about 1 inch in diameter. In two weeks the fruits were one-half rotted (Fig. 118). The decay was fairly soft and watery, possibly a little softer on lemons than on oranges. The breaking down of the flesh extended into the core and the juice sacks. The colors on the surface of the rotted areas were usually dark brown (Ridgway's mummy brown to raw umber) with margins of greenish brown (dresden brown) on the orange and yellowish green (sulfene yellow to citrine) on lemons. Orange fruits, on cutting, showed a yellowish-green color in place of the normal orange color of the flesh. The flesh of the lemon fruits was finally completely broken down. Under moist air conditions, a white fluffy mycelium formed on the surface of the fruits and later the small, spherical, brown-colored sclerotia formed in great quantities. These were yellowish brown (buckthorn brown) at first, changing to cinnamon brown. In the meantime, an amber-colored liquid formed in the inoculated jars.

Causal Agent.—The causal agent is a soil-inhabiting fungus, which is known to attack a very large variety of plants at or below the surface of

---

[1] We are indebted to M. Shapovalov for cultures of this fungus and assistance in inoculation experiments.

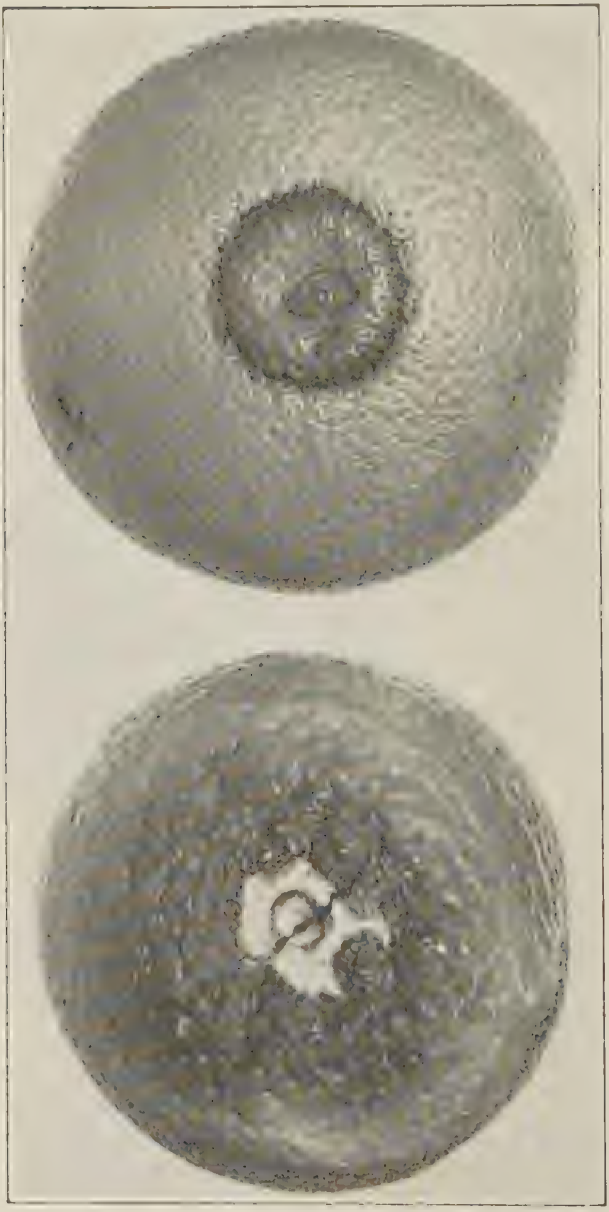

Fig. 118.—Soft rot due to inoculation of oranges with Rolf's Sclerotium fungus *S. rolfsii*. *Upper*, Typical development one week after placing a sclerotium in a puncture at about 70°F. *Lower*, Typical development two weeks after inoculation.

the soil. The mycelium of the fungus in moist atmosphere forms a dense, white, cottony mass of threads. Later, small white tufts appear and gradually assume a rounded form, the sclerotia. These sclerotia are at first white but change through light shades of brown to very dark brown.

The sclerotia are spherical to ellipsoidal, 0.5 to 0.8 millimeter in diameter, smooth and shining (Fig. 119). Shapovalov and Edson (1923) have found different strains of the fungus with sclerotia of different sizes and with marked differences in physiological behavior. The hyphæ are 6 to 8μ in diameter, subhyaline in the interior of the host, but brown with age on the exterior. The hyphæ according to Taubenhaus (1919) are seldom found growing singly, but in groups which tend to anastomose and form strands. The growth at the terminal end of each hypha soon stops, a bud develops near the tip of the terminal cell and this side bud continues the growth.

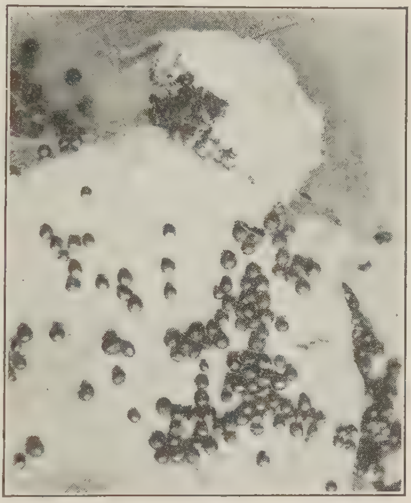

Fig. 119.—Mycelium and sclerotia of *S. Rolfsii* in culture, about one and one-half times natural size. (*After Edson and Shapovalov* (1923).)

OÖSPORA ROT OR SOUR ROT

Sour rot is a soft, slimy, watery, contact decay due to the fungus *Oöspora citri-aurantii* (Ferraris). It was reported by C. O. Smith (1917) as a decay of lemon fruits in California and previously described by Ferraris (1900) as a decay of oranges in southern Europe. A species of Oöspora causing disease in Citrus is also mentioned by Janini (1923) in Spain.

Symptoms.—It is difficult to find adjectives strong enough to describe this rot at its worst. "A putrid, sour, dirty, leaking, maggot-filled mass of mud" partially expresses in the packing-house foreman's mind, the final condition produced by the sour-rot fungus in old mature fruit under the moist humid atmosphere of the packing-house storage room. The tissue softens quickly after infection, becoming even more watery and easily punctured than the green- or blue-mold areas. The decaying areas on mature normally colored lemon fruits may at first become creamy yellow (Ridgway's) naples yellow, then dark-buff yellow (antimony yellow) and finally, as the water-soaked hyphæ show through the skin, a light buff (Ridgway's light buff) (Fig. 122C). The mycelium forms a thin, compact, water-soaked, often somewhat wrinkled layer over the affected surface. The fruit finally collapses and becomes slimy with age and changes into a flattened, watery mass from which liquid drips. It is especially attractive to fruit flies, which breed in it in great numbers.

The initial entrance of the fungus is probably through injuries or through the button of the fruit, from which it readily spreads to other fruit by contact (Fig. 121).

Causal Agent.—The inoculation experiments of Ferraris (1900) and C. O. Smith (1917) have shown that this fungus, *O. citri-aurantii*, may cause an infectious soft rot of oranges as well as lemons and other Citrus fruits. By inoculation into punctures, Smith induced the rot on lemons, oranges, grapefruit and tangerines, the decay beginning to show in forty-eight hours.

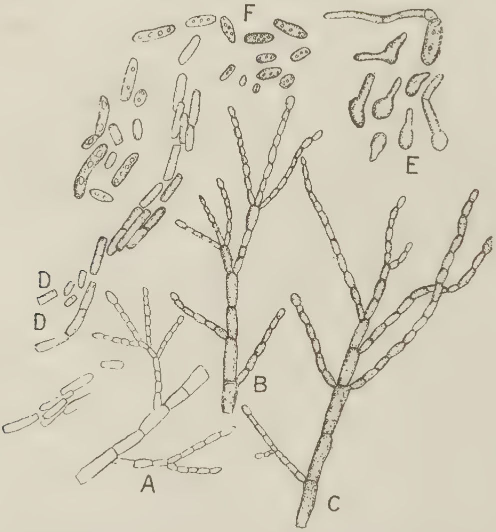

Fig. 120.—Mycelium and spores of the sour rot fungus *Oospora citri aurantii*. A, B, C, aerial hyphae showing chains of spores; D, hyphae separating into cells that function as spores; E, spores in various states of germination; F, older spores containing oil globules. Magnified about 350 diameters. (*After C. O. Smith* (1917).)

Characteristics of the Fungus.—As studied by Smith (1917), *O. citri-aurantii* produces an aereal mycelium on which are produced chains of spores (Fig. 120), 8 to 20 by 5 to 8μ in size. These are oval to oblong in outline and often have obtuse or nearly square ends, and when growing on fruits have oil globules and a granular substance within. The mycelium on Citrus fruits contains granular matter, possibly oil drops, and is 6 to 7μ in diameter. The mycelium also breaks up into innumerable spores. Ferraris reported the size of cylindrical spores as 13.5 to 19 by 7 to 7.5u, oval spores as 9 to 12 by 7.5μ and spherical spores as about 12μ in size. According to C. O. Smith (1917), this fungus is closely related to *O. lactis*, as judged from morphological characters, but he was unable to produce actual decay in lemon fruits by inoculation with the latter fungus obtained from two sources. Smith also found that *O. citri-aurantii* failed to produce the acid reaction in litmus milk shown by *O. lactis*, but produced more uniform and more cylindrical spores than the latter. According to the classification of Sumstine (1913), the fungus would probably be in the genus *Oösporoidea*.

Contributing Conditions.—The age and the condition of the fruit, injuries, humidity and temperature are important contributing factors to the development of sour rot. Recent experiments show that full-sized lemon fruits fresh from the trees are difficult to infect even by puncturing, while older fruit that have been stored are readily infected. Smith also reported that ripe or nearly mature fruit is readily infected, while negative results were frequent with green fruit.

Sour rot is most frequent in fruit that has been held in storage in the packing house for a long time, or in fruit that is naturally weak from some unfavorable growth conditions. Injuries, defects in the skin weak stems or buttons are perhaps necessary to initial infection. After the rot once starts in a box, however, it may spread rapidly by contact. Fruit flies also probably contribute to the general spread of the spores of this fungus in storage after it has started. The sour rot is also frequently associated with other forms of decay. It may start at a small decay area from

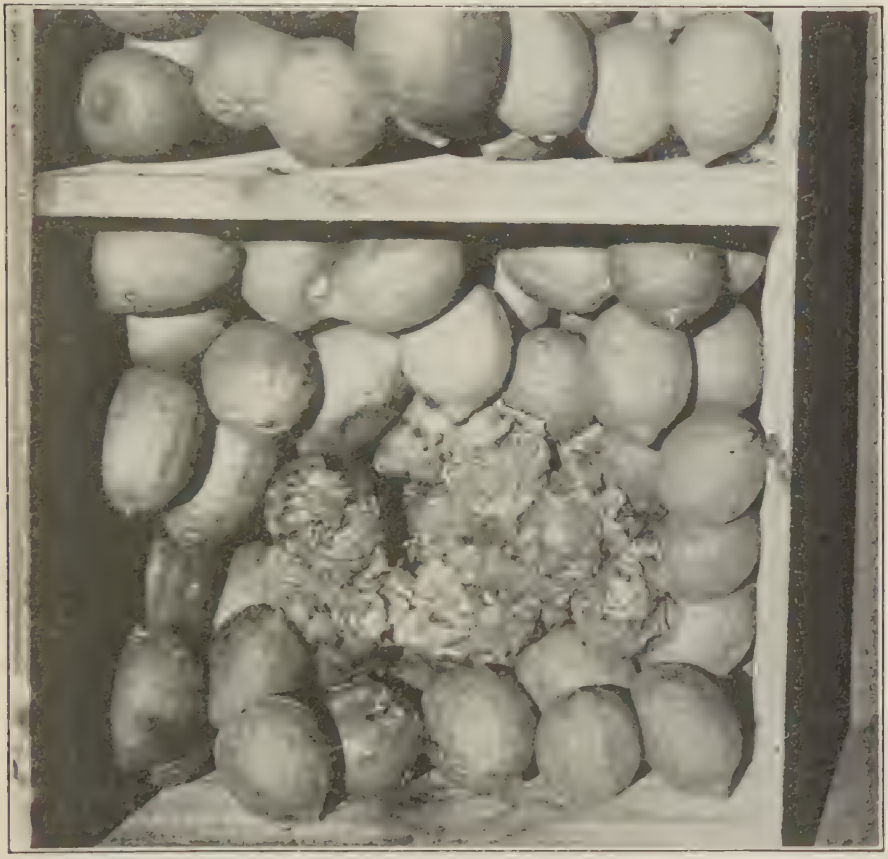

FIG. 121. -Sour rot due to the fungus *Oospora citri-aurantii* spreading by contact in storage. (*After C. O Smith* (1917).)

brown-rot or other organisms and aid in a complete slimy breakdown of the fruit which would otherwise be less watery (Fig. 121).

Control.—The combined methods of control for the green and blue molds and for Pythiacystis rot (brown rot) decay should prevent a large amount of the sour rot, *i.e.*, avoidance of injuries and washing in hot water. If the long storage period for weak lemons is cut down to a few weeks instead of months, very little trouble will usually be experienced. When trouble does occur, frequent inspection of stored fruit is necessary in order to eliminate this contact decay from the stacks. It is one of the most dirty, disagreeable decays to handle when it becomes prevalent. After a bad attack of this decay, it is advisable to clean the floors and walls of the storage rooms and disinfect by spraying with a 4 per cent formalin or copper spray.

PYTHIACYSTIS ROT OR BROWN ROT

Pythiacystis rot or, as it is commonly known by the growers, "brown rot," due to the fungus *Pythiacystis citropthora*, Sm. et Sm. is especially destructive to lemons but may also affect other varieties of Citrus fruits. The trouble occurs in the orchard and the packing house and to some extent in transit. The same fungus is also responsible for Pythiacystis gummosis (see p. 125).

In the orchard, the motile spores which form on the surface of moist soil are splashed by the rains against the low-hanging fruits. Three days to a week, depending on temperature, are required for the decay to become visible. These fruits, if picked in moist weather, carry the fungus to the washing tank, where, if not controlled, it may develop and infect a large percentage of the sound fruits. These, when stored, soon begin to decay, and the fungus mycelium passes from one fruit to another by contact even though no previous injuries are present.

In the rainy season, under California conditions, some infected fruits may even get into the packed boxes and develop brown-rot decay in transit, although at present, with the perfected methods of control, most of these are eliminated before packing.

History and Distribution.—This form of decay on the fruit first attracted serious attention during the period 1901–1905 in California. Before its cause or methods of control were known, it produced excessive decay in lemon fruits and even seriously threatened the life of the lemon industry in that state. The work on the cause and prevention of this rot by R. E. Smith, H. J. Ramsey and others (1907), which began in 1905 in cooperation with the Lemon Men's Club and was followed later by a gradual perfection of the control methods, has resulted in a satisfactory solution of this problem.

Outside of California, what appears to be the same or a similar rot has been reported in Australia by various writers, in Brazil by Avena-

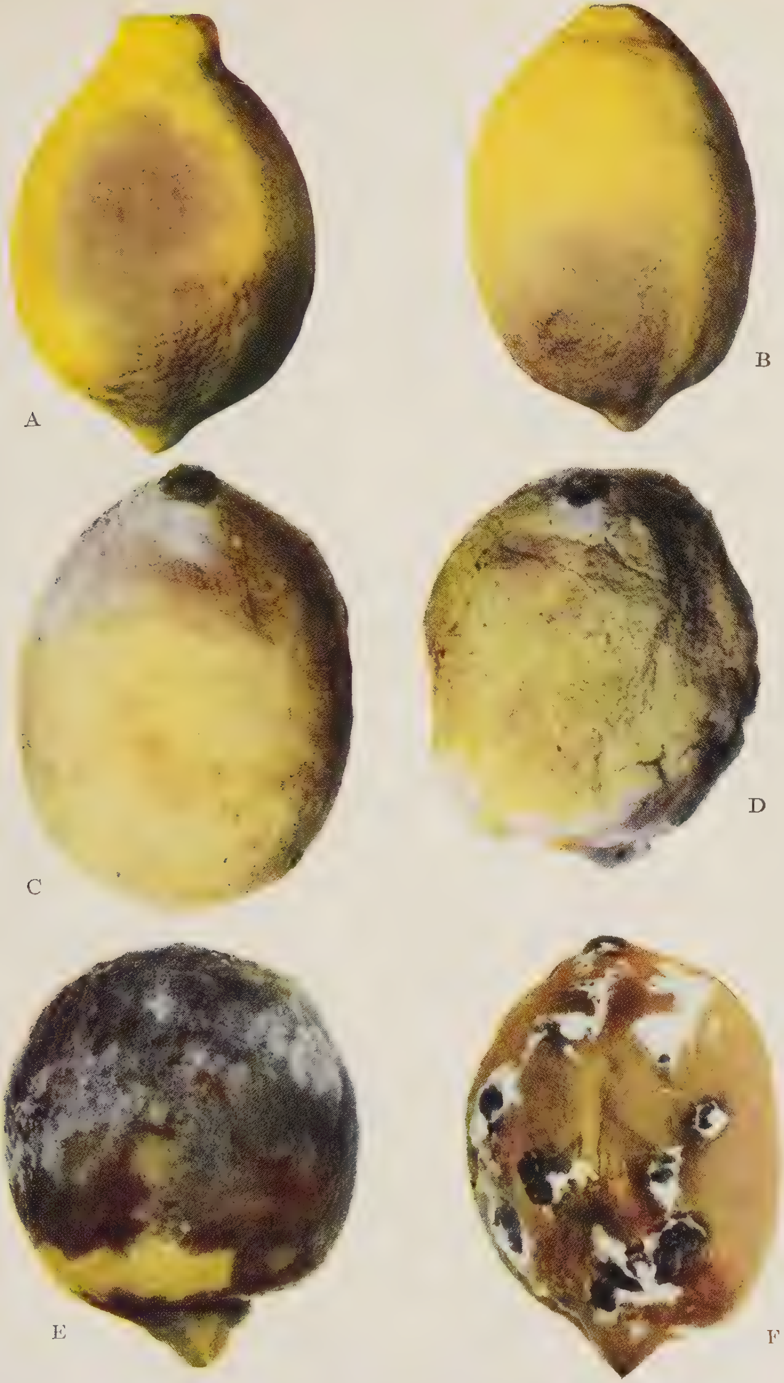

FIG. 122.—Brown rot, sour rot, Botrytis rot and Sclerotinia rot on lemon fruits. A and B, Brown rot due to *Pythiacystis citrophthora*. C and D, Sour rot due to *Oöspora citri-aurantii*. E, Botrytis rot due to *Botrytis cinerea*. F, Sclerotinia or cottony rot due to *Sclerotinia libertiana*.

Sacca, in Hawaii by Pope (1923) and recently in the northern Transvaal of South Africa by Doidge (1925). A few lemon fruits affected by a similar decay were seen by R. E. Smith when traveling in Sicily. A similar disease on Citrus fruits has recently been reported in Portugal by Maia (1925). Brown rot has also been reported doubtfully by H. J. Ramsey from Florida (Fawcett 1915). H. R. Fulton also reports finding one similar case in Florida. The few cases of this rot reported in Florida may have been due to the mal di gomma fungus, *Phytophthora parasitica*, which is now known to be capable of producing a similar decay. Since this last-named fungus is so world wide in distribution (see Mal di Gomma, p. 146 and Phytophthora Rot, p. 379), it is probable that, wherever the conditions of temperature, humidity and other factors are favorable, this brown-rot type of decay may be found.

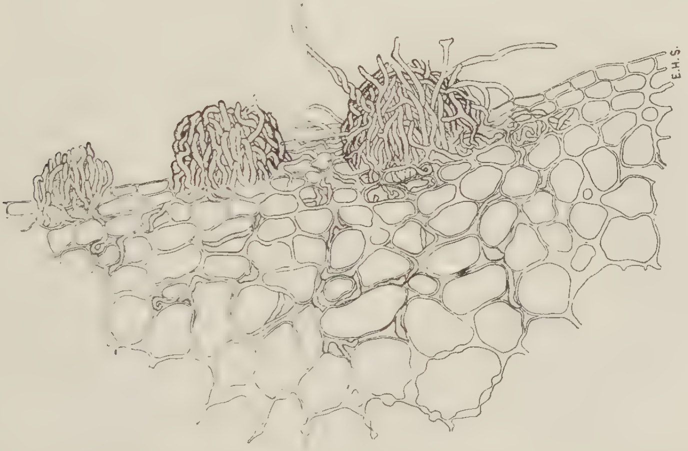

Fig. 123.—Section through the rind of a lemon fruit showing tufts or clusters of hyphae on the surface and hyphae between and within the cells. Magnified about 90 diameters. (*After Smith et al* (1907).)

Symptoms.—In the orchard, brown rot will usually be found, under California conditions, on fruit within 3 feet of the ground. The affected fruit is not at first softened or disintegrated. The rind and underlying tissue remain firm. With lemons, any size and age may be affected on the tree. There is at first only a slight discoloration on the surface extending rapidly from a center of infection (Fig. 122A). On fully colored lemon fruits, the spots as they develop take on various shades of drab and brown (Ridgway's light drab, citrine drab and buffy brown).

In lemon fruits, since the juice is too acid for the growth of the organism, the tissue is affected usually only through to the juice sacks (Fig. 123), but the fungus may sometimes extend finally into the core and divisions. In the open air, there is rarely any visible mold on the surface, but when the fruit is confined in a moist vessel or in a moist storage room, a white, delicate surface mold appears. Supplementing its general appearance, a characteristic odor serves to distinguish it from all other rots. The odor is not especially unpleasant, but has, as R. E. Smith states, "a characteristic rancidity and penetration, originating presumably in a fatty acid produced in the decomposition of the oil in the rind." After this odor is once experienced, it serves as a ready means of identification. There are other forms of decay which leave the fruit somewhat firm but none except the Phytophthora rots have this distinctive odor.

In the packing house, under moist conditions, or in closed boxes on the way to market, in addition to the above characteristics, there is usually a white delicate mold over the surface of the fruit, and the decay soon spreads to the fruits in contact (Fig. 124). Under average conditions, the decay that cannot be seen at the washer begins to show in about five days or a week from the time of storing. The first sign on a green fruit in storage is a small darker green spot shading off imperceptibly into the normal green. This rapidly spreads, and if the air is moist enough, the white, delicate mold appears. In time this may spread to all the fruit in a box. Under moist conditions, the decaying fruits become covered also by the blue and green molds, and by Oöspora or sour-rot fungus, which obscures the brown-rot characteristics. Later, through the effect of secondary decay organisms and maggots of fruit flies, the fruit sinks into a putrid mass. Liquid resulting from decay drips down to other boxes below.

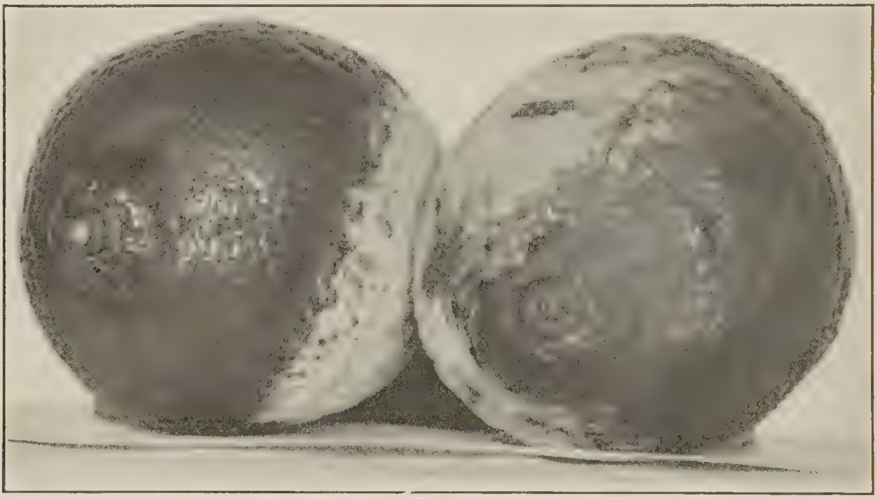

Fig. 124.—White mycelium of brown rot fungus, *Pythiacystis citrophthora*, spreading by contact on fruit in storage, California. (*After Smith and Smith* (1911).)

Causal Agent.—The causal agent of brown rot was shown by R. E. Smith and his associates (1907) to be a soil-inhabiting fungus related to the water molds, which was named and described as *Pythiacystis citroph-*

thora. It lives and propagates best in moist soils, especially those of the heavier type. During periods of rainy, damp weather when the rains and fogs continue during several days at a time, the fungus grows to the surface and produces motile spores that swim about in the films of water by means of cilia (see Figs. 21–23, Chap. IX). During heavy rains, the drops containing the spores spash up against the fruits that are hanging near the surface of the ground and infect them. Except in rare instances, most of the infected fruits are not found more than 2 to 3 feet from the surface of the soil. They are sometimes found higher than this, however, especially when weeds are growing up through the branches of the tree. It is suspected that the spores may sometimes swim up in films of water on the surface of tall weeds, or that they may be carried by insects or be transported in drops of water laterally or even upward by gusts of wind. They may also be transported in bits of mud.

Since these motile spores are killed by drying out, they, as well as the fungus itself, are quite dependent upon moisture. This accounts for the occurrence of brown rot only during the rainy season and for the close relation of Pythiacystis gummosis to excessive moisture in the soil near the trunk of the tree. As has already been pointed out (See Pythiacystis Gummosis and Mal di Gomma, Chap. IX), this fungus appears to be closely related to some of the species of Phytophthora, especially to *P. terrestris.* If its perfect sexual form is found, it will probably prove to be a species of Phytophthora.[1] The technical description has already been given under Pythiacystis Gummosis, page 133.

Contributing Conditions.—The conditions for infection and rapid development of brown rot are primarily excessive moisture over considerable periods of time with moderate temperatures. The ideal conditions for its occurrence in the orchard and the packing house are long periods of rainy and foggy weather (in late winter and early spring in California). The total amount of rainfall is not so important as the length of the moist periods. If the rain lasts for only a day or two, with dry, bright warm periods between, the conditions are not so favorable for brown rot as when the rains and moist weather are continuous for several days or weeks, with little chance for the surface of the soil or fruit to dry out. Under these conditions, a small amount of rainfall distributed over longer periods is sufficient to cause the development of swarm spores and to splash them from the moist surface soil against the low-hanging fruits. No injury is required for infection and entrance in such cases.

Investigations as to the influence of temperature on the fungus have shown that about 80.6°F. (27°C.) is the optimum for most rapid growth of the fungus. The fungus grows fairly well throughout the range from

---

[1] According to a recent publication by Leonian (1925), this fungus is a true Phytophthora, as we have thought for a long time, and he has proposed calling it *Phytophthora citrophthora* (see also Smith and Smith (1925) and Petri (1925)).

56.3 to 86°F., but slowly or not at all below 45.5°F. Development of the disease takes place anywhere between about 55 and 79°F., but not at or above 84.2°F. The spots on fruit develop soonest at 72.5°F. The time elapsing between inoculation by dipping fruit into a suspension of swarm spores and the visible appearance of spots in different temperatures is about as follows: 55.3°F., six days; 60.8°F., three days; 66.2°F., two and one-half days; 72.5°F., two days; 78.8°F., three days; 84.2 and 90°F., no development at all.

The sensitiveness of the fungus to moderately high temperatures for relatively short periods is shown by the following data on hot-water treatment in preventing development of brown rot after infection. Fruits were dipped in suspensions of swarm spores and mycelia of the fungus at about 70°F. (21.1°C.) and then immersed in water at the different temperatures and time periods with the following results (Fawcett 1922*a*):

TABLE 7.—EXPERIMENTS IN PREVENTING BROWN ROT ON LEMONS BY IMMERSION IN WATER AT DIFFERENT TEMPERATURES

Number of fruits	Temperature of water		Time of immersion, in minutes	Percentage of brown rot
	Degrees Fahrenheit	Degrees Centigrade		
50 Control (not infected)	...	....	0	0
40 Control (infected)	...	....	0	100
20	70	21.1	2	100
30	70	....	3	100
20	90	32.2	3	100
20	100	37.8	3	100
20	105	40.5	½	100
20	105	....	1	100
20	105	....	2	100
20	105	....	3	100
20	105	....	4	100
20	110	43.3	½	100
30	110	....	1	95
20	110	....	2	60
20	110	....	3	10
20	110	....	4	55
20	115	46.1	½	100
30	115	....	1	0
28	115	....	2	0
30	115	....	3	0
30	115	....	4	0
20	120	48.9	½	0
40	120	....	1	0
50	120	....	2	0
40	120	....	3	0
30	120	....	4	0

An example of conditions that especially favored brown rot occurred at Whittier, Cal., in the spring of 1922. A heavy rain on May 10 was followed by cloudy weather, producing a condition for the Pythiacystis fungus to grow to the surface and form its swarm spores in great numbers. Then another hard rain on May 20 splashed the swarm spores onto the lower fruits. Large quantities of lemon fruits picked a few days later were placed in storage for curing. A large percentage of these had been infected in the orchard, but there had not been time for the rot to develop at time of picking. They soon began to decay rapidly, the rot spread by contact and hundreds of boxes were destroyed.

Control.—Effective methods have been worked out for the prevention of this rot both in the orchard and in the packing house. The spores and mycelium of the fungus are very sensitive to certain disinfectants and to high temperatures, and these are made use of in its control.

In the Orchard.—As before stated, the fruit is affected in the orchard usually only on the lower branches within 3 feet of the soil and after continuous periods of rains during which the swarm spores are splashed by rain drops onto the low-hanging fruits. The method of preventing the disease now most widely practiced under California conditions is to spray the ground and lower branches for a distance of 3 feet from the soil with Bordeaux mixture. The 3-3-50 formula (3 pounds copper sulfate, 3 pounds of lime to 50 gallons of water) has been found effective. This should be done in the fall, in October or November preceding the period when continuous rains may be expected. If rains begin early, spraying is effective if done after the first rains, as it is usually not the first hard shower that causes infection. This first rain, however (if the surface soil remains moist for a few days), may allow the fungus to grow to the surface and develop sufficiently so that the spores will be ready with the next hard rain to be splashed against the low-hanging fruits. The spraying should be thorough so as to cover well the entire surfaces of soil, leaves, twigs and fruit near the ground. Where there are tall weeds or other plants growing up through and touching the lower branches, these should be cut and allowed to lie on the soil. If fruits on the ground and lower branches are already affected, these should be placed in the middle of the rows between the trees or destroyed. They are a menace if allowed to get next to the trunk, as they increase the liability to Pythiacystis gummosis.

While spraying for the prevention of brown rot, it is important also to drench the trunks very thoroughly with the same spray, as a prevention against the associated disease, Pythiacystis gummosis (see p. 125). A season especially favorable to brown rot of the fruit is liable to be followed by an increase of this type of gummosis, if not prevented.

If spraying has not been done and a bad season for brown rot occurs, it may be necessary in picking to keep the lower and upper fruit separate.

This may be advisable in order to facilitate the elimination of brown rot at the packing house and to help prevent spread by contact with sound fruit. Some lemon cooperative associations in California commonly practice this method of picking all the lower fruits separately during the season for brown rot. Growers in some sections where brown rot is only occasionally severe prefer to take the chance of occasional losses rather than bear the yearly expense of spraying for prevention.

The precautions against placing the picked fruit on the moist soil in the orchard, or allowing it to remain in the boxes on the soil during a foggy or rainy period, or allowing the boxes to become contaminated with muddy water or excessively wet soil particles may be mentioned here.

The placing of straw or other material over the surface of the soil was at one time practiced to a certain extent and was fairly effective in keeping down infection in the orchard. This practice, however, has been almost entirely superseded in recent years by spraying.

In the Packing House.—If the brown rot is not prevented in the orchard and the apparently sound fruits remaining are put through the washing machine preparatory to curing, there are usually a number of fruits so slightly affected as to escape notice. These are capable of contaminating the wash water so that a large number of healthy fruits are infected and later contract brown rot. These by contact in the boxes often cause large losses. It was found that the use of a very small percentage of copper sulfate in the wash water would effectively prevent such infection in washing (R. E. Smith *et al.* 1907). The amount now used in common practice is from 1 to 2 pounds of copper sulfate to every 1000 gallons of water. The copper sulfate (blue stone) for a stock solution may be dissolved at the rate of 1 pound to each gallon of water in a wooden barrel or earthenware vessel by suspending the copper sulfate in a porous sack at the top of the water. About 1½ gallons of this may then be poured into each 1000 gallons of wash water. When fruit is washed in cool water during seasons of brown rot, this precaution should always be taken. When, however, water sufficiently hot is used (115 to 125°F.), the addition of the copper sulfate is not so necessary.

Some years ago, certain California packing houses began using hot water for the purpose of more readily cleansing lemons. It was found that brown rot was also apparently controlled even when the copper sulfate was omitted. An investigation was made by Fawcett (1922*a*) of the effect of hot water at various temperatures and times on the fungus, with the result that hot water without or in addition to the copper sulfate has come to be largely used in large lemon packing houses for brown-rot control. A temperature of 115°F. acting for two minutes or 120°F. for one minute was found to prevent development. A temperature of 120°F. for two minutes was found to prevent development even if applied thirty hours after spores had been placed on them. With the copper sulfate teratment, development was not prevented if only five hours had elapsed before application (Fawcett 1922*a*).

Two methods of heating the water are practiced:

1. A series of gas jets is placed directly under the washing tank, and the desired temperature is kept by increasing or diminishing the flame or is kept constant in some cases by thermo-regulators.

2. A separate heating unit is built to heat the water, from which it is circulated through the washing tank to give the required temperature.

If no means is taken to prevent infection at the washer with either disinfectant or hot water, one brown rot fruit or bits of moist soil or trash may be sufficient to contaminate the water and infect a large percentage of fruit. Many instances of this took place in packing houses before the cause and prevention were known. But even with all precautions, some fruits just on the point of development of the rot will later develop it in the storage rooms. The occurrence of even a few such fruits make their presence known to the experienced operator by the odor. One such fruit in a large stack of boxes may be ferreted out by sniffing about till the exact location is determined.

The usual practice when these are found is to examine the boxes, take out the decayed fruits and segregate the "contacts," *i.e.*, every lemon fruit that has touched a diseased one, and watch these contacts for possible further development. It would probably prevent part of this development in the contacts if they were subjected to hot water 115 to 120°F. for two or three minutes before being again set aside.

PHYTOPHTHORA ROT

A decay of Citrus fruits resembling brown rot or Pythiacystis rot may be produced by species of Phytophthora. It was shown by inoculation experiments, a number of years ago, that *Phytophthora* (*terrestris*) *parasitica* was capable of producing a rot very similar to that produced by *Pythiacystis citrophthora* (p. 372).

A rot of Citrus fruits in Western Australia which was formerly identified as that due to Pythiacystis is now thought to be due to a new species of Phytophthora as reported by Carne (1924).[1] Phytophthora rots similar to the brown rot described by R. E. Smith *et al.* (1907) will probably be found to occur wherever *P. parasitica* or similar Phytophthorae are found, provided the moisture and temperature conditions are suitable for infection. The Western Australian Phytophthora was found not only causing a serious rot of orange and mandarin fruits but also a serious leaf and twig blight (Chap. XIII).

---

[1] A publication by Carne has just been received in which he describes the West Australian Phytophthora as a new species, *P. hibernalis*. The conidia are $17 - 56 \times 10 - 28\mu$ with an average ratio of length to breadth of 2.3. The oospores are $22\text{–}45.6\mu$. The optimum temperature for growth is remarkably low—about 53.6°F. (12°C.) (Carne, W. M., Jour. Roy. Soc., Western Australia **12**: 13-41, 5 pl., Dec., 1925).

Contributing Conditions.—Like the brown rot due to Pythiacystis, it occurs after the first soaking rains in the autumn and recurs with very wet periods. Carne reports that trees next to permanent water on the wettest soil or on land flooded by a stream are the most seriously attacked. Like the Pythiacystis, the fungus grows to the surface after rains and is splashed or blown to the lower fruits and leaves by rains. It is, therefore, closely associated with wet weather. The south or shaded sides of the leaves in Australia remain wet longest and are the most apt to be affected. It is then flecked by the wind-blown branches to any height in the tree.

No evidence is reported that this rot spreads by contact with fruit after being picked. Losses as high as 50 per cent of the crop are mentioned. All varieties are attacked, but the early varieties suffer most. The fruits are not affected while green, but become susceptible as they begin to mature.

Symptoms.—As has been mentioned, Phytophthora rot is similar to the brown rot. Carne describes this rot in Australia as beginning with a dull circular mark at first, usually on one side, and later spreading over the entire fruit. When the affected fruits begin to dry, they become dark in color. The fruits in contact with the soil are the first infected; later, fruits almost any height in the tree may become infected; fruits in clusters become affected by contact one with the other. In time, the fruits become distinctly odorous, followed by the sour, soft, greasy rot, and collapse into a wet slimy mass. This mention of the sour, greasy rot suggests the sour rot or Oöspora rot which in California (p. 374) often accompanies or follows brown rot.

The Control.—The treatment recommended for this decay by Carne is Bordeaux mixture 4-4-50 or Burgundy mixture 4-6-50 at the end of April or early May in Western Australia; also that the fallen fruits be picked up and carted to places well away from the orchard.

SCLEROTINIA ROT OR COTTONY ROT

Cottony rot due to the fungus *Sclerotinia libertiana* is frequently a serious, rapidly progressing contact decay, especially in lemon fruits in California (C. O. Smith 1910, 1916*a*, 1916*b*). It has not apparently been reported as a serious disease of Citrus fruits in other Citrus countries, although Adams (1923) has reported it in Australia. The same organism causing cottony rot also affects, under certain conditions, the twigs, branches, trunk and even the roots (Chaps. VIII, IX, XIV). It is a widely distributed fungus causing blights, rots and other effects on a great variety of hosts.

Symptoms.—The affected fruits are covered with a white cottony or fluffy growth of mycelium which later forms cheesy, irregular, black, compact bodies (sclerotia) which somewhat resemble seeds and in a general way suggest the black, dry feces left by rats. The very first

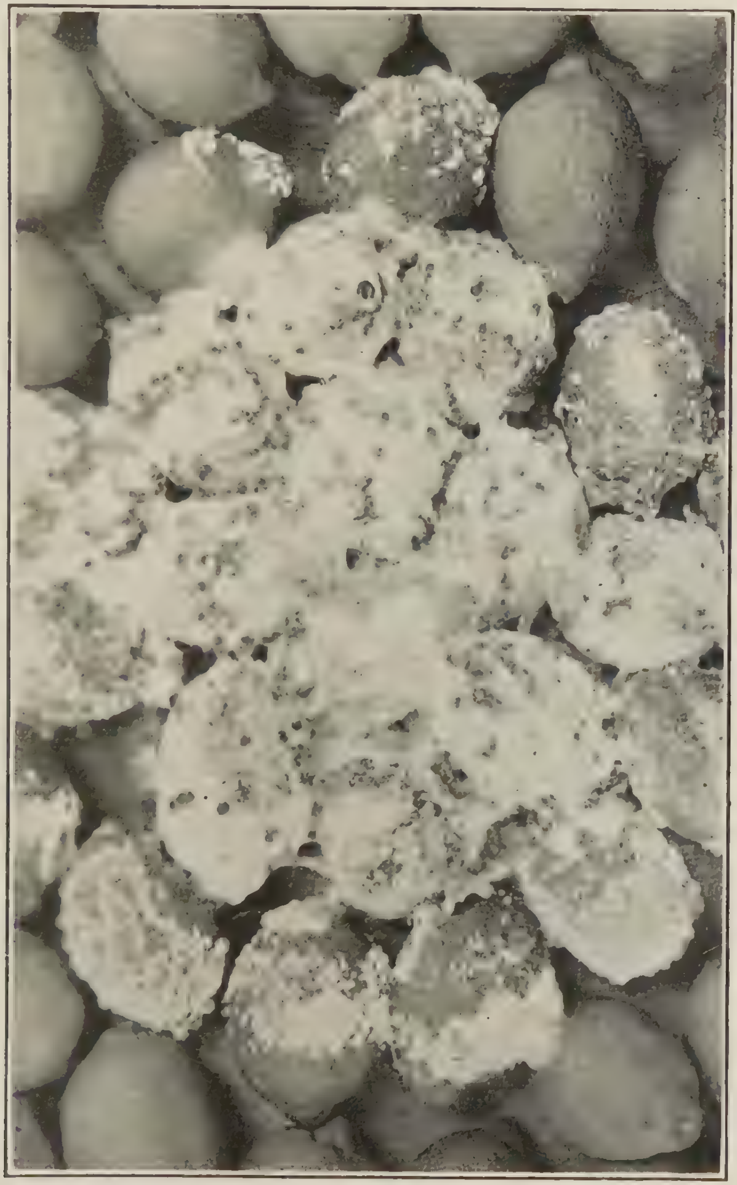

FIG. 125.—Lemon fruits being destroyed by Sclerotinia rot spreading by contact in packing house trays, California. (*After C. O. Smith* (1916b).)

symptom is an area almost imperceptibly discolored, but still firm, without any visible growth on the surface. Softening is slow and the skin is at first leathery and pliable. On mature lemon fruits, the color of the surface in dry atmosphere is often buff yellow (Ridgway's antimony yellow) soon changing to yellowish brown or greenish brown (buckthorn brown or dresden brown), if conditions are too dry for surface mycelia. If the air is moist, the cottony growth appears rapidly, followed by the black sclerotia (Fig. 122F). It is one of the most rapidly spreading contact rots under moderate or cool storage conditions, sometimes attacking almost every fruit in a box and spreading through it to adjoining boxes (Fig. 125). In winter and spring, in wet seasons in California, this is a rather serious contact rot of lemons in packing-house storage, as well as in transit.

Method of Infection and Development.—As shown by a large series of experiments by C. O. Smith (1916*a*), the decay is induced on both ripe

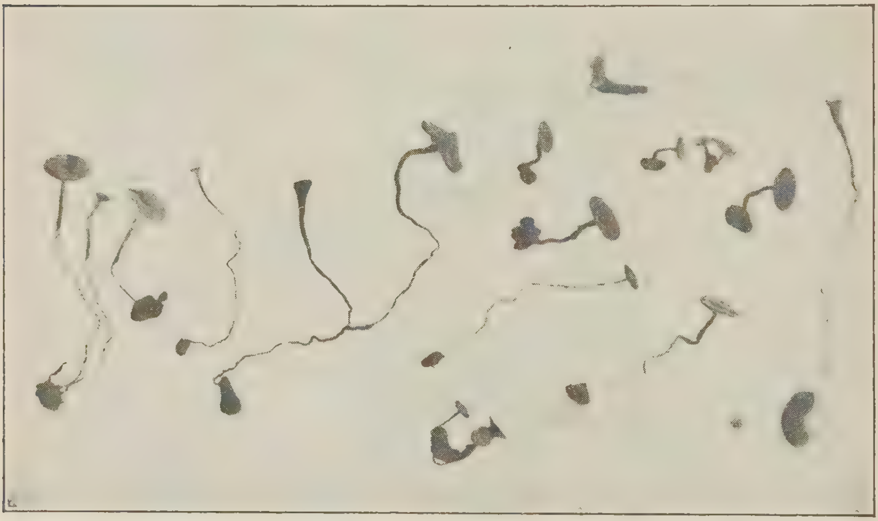

Fig. 126.—Apothecial or spore stage of the cottony rot fungus *Sclerotinia libertiana*. About natural size. (*After C. O. Smith* (1916*b*).)

and green fruit in moist atmospheres: (1) by placing the mycelia or sclerotia in the tissue through a puncture or injury; (2) by placing mycelia on the uninjured surface of the fruit, especially along with other dead organic matter; (3) by placing a piece of an apothecium in the tissue through a puncture or injury; (4) by atomizing spores on the surface, in which case infection occurs only at the button and blossom ends and at points in contact with each other or with the moist chamber; (5) by inoculating the stem and blossom ends with mycelium of the fungus. Spores, however, placed in drops of water or in prune juice on the surface of uninjured fruits were unable to induce decay.

Life History and Characteristics of the Fungus.—The complete life cycle of the fungus occurs in three stages, very different in appearance and also in function: (1) the vegetative stage, (2) the sclerotial or resting stage and (3) the apothecial or spore stage. Beginning with the germination of the spores, there is formed first the vegetative hyphæ, which either penetrate directly if a wound is present or grow first into a bit of organic matter from which the germ tubes are capable of entering the sound uninjured tissue and begin to break it down. By rapid vegetative growth the fruit is rotted, and white cottony mycelium appears later on the surface. Masses of this mycelium coalesce to form black, firm, seed-like bodies (sclerotia) (Fig. 122F). These are capable of resisting hot dry periods and cold freezing conditions. In this respect, they function like seeds of higher plants. After a period of rest which takes them through to the next rainy season in autumn and winter in California, and with favorable conditions of moisture and temperature, these give rise either to the vegetative mycelia again or to the funnel-shaped small bodies (apothecia) containing spores in their cup-like disks (Fig. 126). The spores are borne in long cylindrical sacks (asci) microscopic in size (Fig. 127). These spores when mature are often discharged or shot out forcibly from the apothecium as small clouds of dust. These may be borne by currents of air to the fruit and twigs on the tree or on the fruit as it is being picked and placed in the boxes. They may also be carried to the cover crops and infect them. An injury to the fruit or a small bit of organic matter will again furnish conditions for the vegetative stage and the beginnings of decay. The technical description with measurements for the different stages and organs of this fungus are about as follows:

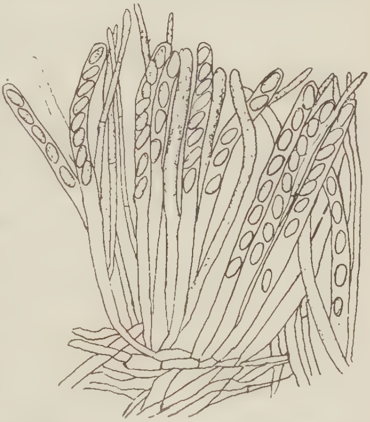

FIG. 127.—Section through an apothecium showing the spores in long sacks (asci). Magnified about 300 diameters. (*After C. O. Smith* (1916*b*).)

Sclerotinia libertiana Fcl. Sclerotia a few millimeters to 2 centimeters or more in length, black on the surface, light colored within; apothecia pale to brown in color, 4 to 8 millimeters broad, funnel shaped with cup-shaped disk with slender stems. Asci cylindric, 130 to 135 by 8 to 10μ, very slightly bluish; spores ellipsoid usually minutely guttulate, 9 to 13 by 4 to 6.5μ; paraphyses clavate (Fig. 127). The vegetative hyphæ are composed of long-branched cells. In the host tissue, these are frequently thicker, more branched and crooked and more septate than those outside. Attachment organs composed of close compact branches are formed by the aerial hyphæ when they come in contact with a solid object. The sclerotia appear to be formed when the food supply is exhausted. The mycelia first become dense in spots; then there is coalescing of hyphæ with formation of a white to pink body, gradually becoming smooth and black on the surface. These sclerotia may remain dormant in the soil for long periods. When they germinate, sprout-like organs are produced which grow to the surface. On reaching the light, these "sprouts" thicken and produce the apothecium (Fig. 126). These apothecial bodies 4 to 8 millimeters or more broad are at first inverted cone shaped but later by a recurving of the top become funnel shaped with a "cupping" of the top in the surface of which the spores are borne in the cylindrical asci.

Contributing Conditions.—The conditions favoring this decay are mainly cool or moderate temperatures, with a moisture favorable to the germination of spores and development of the fungus. Dead tissue or organic matter of any sort in contact with the sound tissue is an important condition for infection and development. The germinating spores do not seem to be capable of readily entering sound tissues at once, but must use this indirect method for invasion. In the orchard, a dense growth of cover crop and organic matter in the soil with moist periods and cool to moderate temperatures afford the conditions favorable to the development and infection of twigs and fruit. In the packing house, the lemon fruits are usually left in the curing rooms or tents for six to eight weeks after being washed. The humidity is usually not allowed to be below 80 per cent in order to prevent wilting. This humidity is suitable for cottony rot development if fruit has become infected in the orchard. Such infection in California usually occurs only from January to May and after that time almost completely disappears (C. O. Smith 1916*b*).

In fruit stacked closely together under poor ventilation and high humidity, the cottony rot when once started will spread rapidly by contact, the fungus from one diseased fruit sometimes spreading throughout the box and rotting nearly every lemon and sometimes spreading through to the next box (Fig. 125). Even the wood of the boxes, if moist, becomes covered with the white mycelium of the fungus.

Control.—Cottony rot of fruit develops, as a rule, only in the packing house or in transit and not in the orchard. The spore stage of the fungus, however, occurs only in the orchard, chiefly where there is sufficient vegetable organic matter and moisture, such as is found in dense cover crops or other natural vegetation. The very conditions best suited to good growth and crop production are often those also suitable for the fungus. Most growers prefer to lose some fruit by cottony rot than to do away with organic matter and cover crops. If, however, the fungus becomes too prevalent, especially on heavy soils, there may be danger from root, trunk and twig attack in the orchard as well as fruit attack in the packing house (see Chaps. VIII, IX, XIV). Under such conditions, it may be advisable to discontinue cover crops temporarily for one or two years and then resume the practice. In picking, washing and curing fruit from orchards likely to be infected, certain precautions should be taken: (1) Boxes should not be allowed, either empty or with fruit in them, to remain long on the ground where they may become infected by resting on the diseased cover crops. (2) The same care should be used to avoid injuries as to prevent green and blue mold, since cottony rot also starts most easily at injuries. (3) The fruit should be kept as free as possible from contact with organic matter, trash, bits of dirt, etc., in the field boxes, since such organic matter aids infection and development of the decay. (4) Field boxes in which the sides or bottom have been previously in contact with cottony rot fruits should not be used unless they are sterilized in 5 per cent formalin or steam. (5) The fruit should be washed in hot water as for brown rot. (6) In storage, the humidity should be kept as low as possible without injury to the fruit, and good ventilation between boxes should be provided. (7) Inspection should be frequently made and all diseased fruit removed to prevent rapid decay by contact. (8) When possible, all the "contacted" fruit should be kept separate. These suggestions apply to Botrytis rot as well.

BOTRYTIS ROT

The Botrytis rot or "gray mold" due to the fungus *Botrytis cinerea* is usually more frequent in lemon than in orange fruits. It is usually only a storage and transportation decay, but may also occur in the orchard. Like the cottony rot or Sclerotinia decay, it spreads by contact, but less rapidly than the latter. The Botrytis fungus also has the same ability as the Sclerotinia fungus of developing at very low temperatures and can develop slowly even at a temperature of 32°F.

History and Distribution.—Botrytis rot of lemon fruits has been recognized for a long time in California. It also occurs to a certain extent on other varieties, as on oranges. It, or closely related fungi, is widely distributed and causes rots of various fruits and vegetables. The same fungus is found on twigs, leaves, branches and bark (Chaps. X, XIV). This fungus has been reported on Citrus fruit in storage in Australia (Adams 1923), but, as far as is known, does not cause trouble in Florida, the West Indies or definitely tropical countries. It, or closely related fungi, has been reported on Citrus in Spain (*B. vulgaris* Fr. by Janini 1923) and Italy (*B. citricola* by Brizi 1903).

Symptoms.—The initial stage of Botrytis decay, before the distinct colors appear, is somewhat the same as that induced by Sclerotinia. Its main characteristic in later stages is the gray instead of the white mold over the surface (Fig. 122E). This decay may start either at the "button" or cut stem or at injuries on the side. It often proceeds from bits of organic matter through the uninjured rind. The affected area, before the surface mold appears, is at first firm and later becomes leathery and pliable like that of the Sclerotinia rot, but darker than the latter. On lemons, the surface becomes cinnamon drab or cinnamon brown (Ridgway the same) and may later take on shades of buff brown or dark brown (sayal brown, Prout's brown or even Mars brown). The rind, core and membranes are invaded faster than the pulp. On oranges, the colors may be medium to dark yellowish brown (sudan brown or brussels brown). At 60 to 70°F., Citrus fruits may become entirely rotted in two weeks or less from time of inoculation. If the air is moist, the mycelium soon appears, and as the spores develop, the surface gradually presents a light neutral gray to a deep gull-gray appearance. The color of the invaded tissue within usually remains nearly normal in color during the initial stages.

R. E. Smith (1902) described the action of the fungus on plant tissue as a disintegration of protoplasm, separation of the cells one from the other and finally a collapse, the tissue being affected considerable distances from the fungus filaments.

Causal Agent.—The fungus, now generally known as *Botrytis cinerea*, but which has also been designated by some authors as *B. vulgaris* (R. E. and E. H. Smith 1911), is widely distributed and has been reported on a large number of host plants. Its vegetative stage is quite similar to *Sclerotinia libertiana*, but it differs markedly in producing the conidial stage with imperfect spores and not producing the sclerotia readily on the host. Sclerotia, usually smaller than those of *S. libertiana*, are produced on some culture media. No perfect or apothecial stage has been seen under California conditions. The growth is made up of vegetative hyphæ, on which are borne the outwardly extending fruiting hyphæ (conidiophores), bearing the numerous spores at the ends of their branches (Fig. 128). These vary in size according to surrounding conditions.

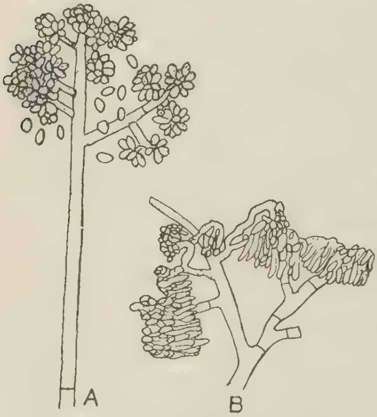

FIG. 128.—*Botrytis cinerea:* A, spore-bearing stalk (conidiophore) and spores of the fungus; B, hyphae with organ of attachment. (*After R. E. Smith* (1900).)

The hyphæ are gray, greenish gray, or dark olive, conidiophores septate 11 to 23μ in diameter with dark-brown tint, branches hyaline with rounded ends, each ultimate branch bearing three or more globose pale-colored spores. Spores 9 to 12μ long by 6.5 to 10μ broad, (Lindau 1907). This fungus develops sclerotia (Fig. 51) in culture media, but these have not been seen on the decayed fruits. They vary in size but may average 5 to 8 millimeters in diameter.

Contributing Conditions.—The favorable conditions for Botrytis rot of lemons are long periods of moist weather with low or moderate temperature, injuries to the fruit or bits of organic matter in contact with them. This decay is usually found only in the packing house and in transit, but under certain sets of conditions may also cause trouble in the orchard.

An example of an unusual set of conditions in which Botrytis rot became very serious on Valencia oranges was noted in Orange County, California, in 1915. During April and the first five days of May, the sun was almost continuously obscured by clouds. Eleven of the last fifteen days of that period were rainy, and the temperatures were low or

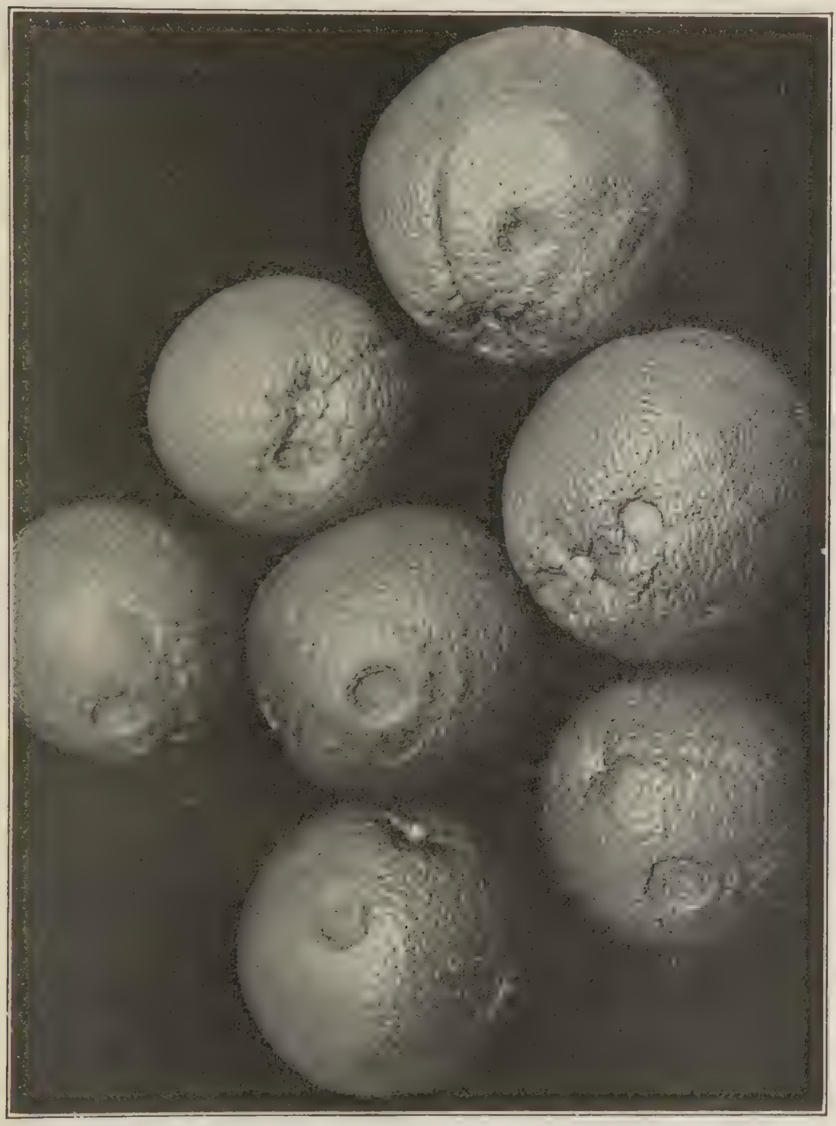

Fig. 129.—Valencia oranges as they came from the tree showing spots produced under moist atmospheric conditions by the fungus *Botrytis cinerea* entering from bits of fallen petals, California. *(Photo by C. O. Smith.)*

moderate, with a mean of 55.4°F. Many of the moist petals in falling lodged upon or stuck to the Valencia-orange crop of the previous year, which was still on the tree. These petals contained the fungus *Botrytis cinerea*. The constant moisture and moderately low temperatures were favorable for its development. The rind was softened (Fig. 129) and the fruit destroyed wherever the petals lodged upon it. Here we had the factors of: (1) temperature; (2) moisture; (3) sufficient duration of the first two factors without the drying effect of sunshine; (4) the presence of falling petals; (5) the presence of a previous crop; and (6) a parasitic fungus. If any one of these six factors had been slightly different or absent, the oranges would not have been destroyed in this way.

The fungus lives on a variety of decaying matter, such as leaves, petals, twigs, fruit, bits of wood or other vegetable matter in the tree or soil. The spores may be carried by wind, water, insects or other carriers to the surface of the tissues, where they may germinate and enter wounds. Under favorable conditions, the fungus may gain entrance to uninjured tissue if this tissue is in direct contact with organic matter or dead cells into which the fungus has first penetrated. Slight frost injury will also render tissue more susceptible to the fungus. In the lemon storage rooms, very high humidity, lack of ventilation, weak fruit and injuries may all be contributing factors.

Control.—The Botrytis rot, as a rule, is not so serious as the Sclerotinia or cottony rot. Under special climatic conditions, however, such as described under contributing conditions, its control in the orchard would probably be very difficult. It would be nearly impossible to grow oranges without a system of protective spraying in a region where such a set of conditions was prevalent every season.

The principles of control for Botrytis rot of lemons are the same as for that of Sclerotinia or cottony rot, which are given at some length on page 384. They are, briefly stated: (1) to avoid leaving boxes long on the ground in moist weather, either empty or with fruit in them; (2) to use care in preventing injuries; (3) to keep fruit free from contact with organic matter and trash; (4) to wash the fruit in hot water; (5) to keep the humidity in storage room as low as feasible and to provide ventilation between the stacks; and (6) to inspect the boxes frequently in order to remove any decaying fruit.

HYALINE ROT

In Japan, a Citrus fruit known as "natsu mikan" (summer orange) is commonly grown, and as the fruits approach maturity on the tree they frequently become affected with a serious rot which renders them unfit for eating and often causes them to drop from the tree. This rot also occurs in storage, in transit and on the markets. The natsu mikan is not known or at least is not grown commercially in other countries, and its botanical position has not been determined; the fruits are similar in taste to the American-grown grapefruits (*Citrus maxima* var. *uvacarpa*) but are somewhat smaller in size and have foliage and flowers much more nearly like the sour orange (*C. aurantium*). The disease is of major importance to producers of the natsu mikan in Japan, but, because the commercially grown fruits of other countries are not widely planted in Japan, there is no knowledge as to their susceptibility to this disease. It is known, however, that the mandarin oranges, Satsuma oranges, navel oranges and East Indian pummelos are not susceptible under the orchard conditions of Japan.

Symptoms and Causal Agent.—Fruits hanging on the tree nearest the ground are most commonly affected. Small, hyaline, watery-appearing areas occur on the rind more commonly near the blossom end. The area spreads rapidly, and fruits may be observed commonly with one-third to one-half of the area affected while still hanging on the tree. There is no development of fungus fructifications nor blackening nor discoloration other than the watery appearance. On cutting into the fruit, the flesh is found to have a similar watery appearance and a slightly abnormal odor of decay. There is, however, no visible mycelium or direct evidence of fungus infection to the naked eye other than the pathological symptoms.

A fungus can be readily isolated, which, upon inoculation into normal mature fruits, will reproduce the rot. The fungus, in culture, forms a thick, felty, white mycelium, but no fructifications are formed under usual cultural conditions of the laboratory. Since the fungus is sterile, its systematic position has not been possible to ascertain. Judging from the symptoms on fruit, the fungus is possibly related to Phytophthora.

Prevention.—This is another of the diseases which is of limited occurrence at the present time, the spread of which to new countries should be restricted by measures for inspection and quarantine. The disease occurs during the summer season in Japan when the temperatures are high. It is, therefore, apparently a warm-weather disease. In warmer countries, it is conceivable, from analogy with other introduced diseases, that other Citrus hosts would possibly be susceptible and severely affected. Entire exclusion of this trouble is, therefore, the most economical preventive measure for other Citrus-growing countries.

Although no experiments have been conducted on control measures in Japan, spraying with fungicides as the fruits approach maturity, as is done for brown rot of lemons in California, would be promising projects for investigation.

ALTERNARIA ROT OF LEMONS

The Alternaria rot of lemons is largely a decay of weak fruit or fruit that has been held in the packing house or storage for a long time. (Alternaria or black rot of oranges is discussed separately.) For the most part, it affects the central core and stem end and is frequently known as "center rot." It is aided to a large extent under California conditions by internal decline, membranous stain, sunburning, drought effects, slight frost injuries or internal changes that tend to weaken the fruit physiologically. Lemon fruits which are sound internally as well as externally are very resistant to it. Recent inoculation experiments indicate that strong fresh fruits directly from the tree are not easily infected even by puncturing, while older fruit of the same kind after eight weeks of storage are readily infected. These results agree with previous experiments and observations.

History and Distribution.—Attention was first called to the prevalence of Alternaria rot in lemons along with internal decline in California soon after the severe freeze in 1913. Preliminary observations were first made by Tylor of the University of California, who found Alternaria commonly associated with internal decline and membranosis and produced decay of this type by inoculation experiments. It was later studied by the writer and others of the Citrus Experiment Station and generally thought to be associated with fruit that was physiologically weak internally. It was more extensively studied by Bartholomew (1923*a*), who found that the Alternaria fungus was present in the buttons on fruit in the orchard even at an early age in its development, that it advanced from the button through the core when the condition of the fruit became favorable, that the rot has an apparent relation to the age of the fruit and to the weakness of the fruit brought about by internal decline, frost, or other effects and that the fungus could not be entirely killed in the buttons by many of the usually employed fungicides except at strengths that were injurious to the fruit.

Symptoms.—The Alternaria rot on lemons takes at least two forms, depending on maturity and age of fruit and other factors:

1. Its most characteristic form on mature fruit is a soft breakdown of the central axis or core, brought about by the fungus entering from the "button" or stem end. The fruit may appear sound on the exterior, but under slight pressure it crushes easily, the rind breaks open on one side and juice or the disintegrating tissues escape. This soft disintegrated condition of the interior is strikingly different from the dry, firm, black rot of oranges due to a similar fungus.

In the "center rot" type of Alternaria decay of lemons, the button first blackens and then a very slow discoloration proceeds along the central axis and also to a certain extent along the inner tissue of the rind without at first visibly affecting the exterior (Fig. 130A–D). For a long time the fruit remains firm, but after considerable development of the fungus internally, the central portion, especially that near the stylar end if internal decline has preceded it, becomes soft, brown and watery. Later, the discoloration shows through the yet unbroken rind as a translucent, dull, dark-colored area at some point where it will soon afterwards

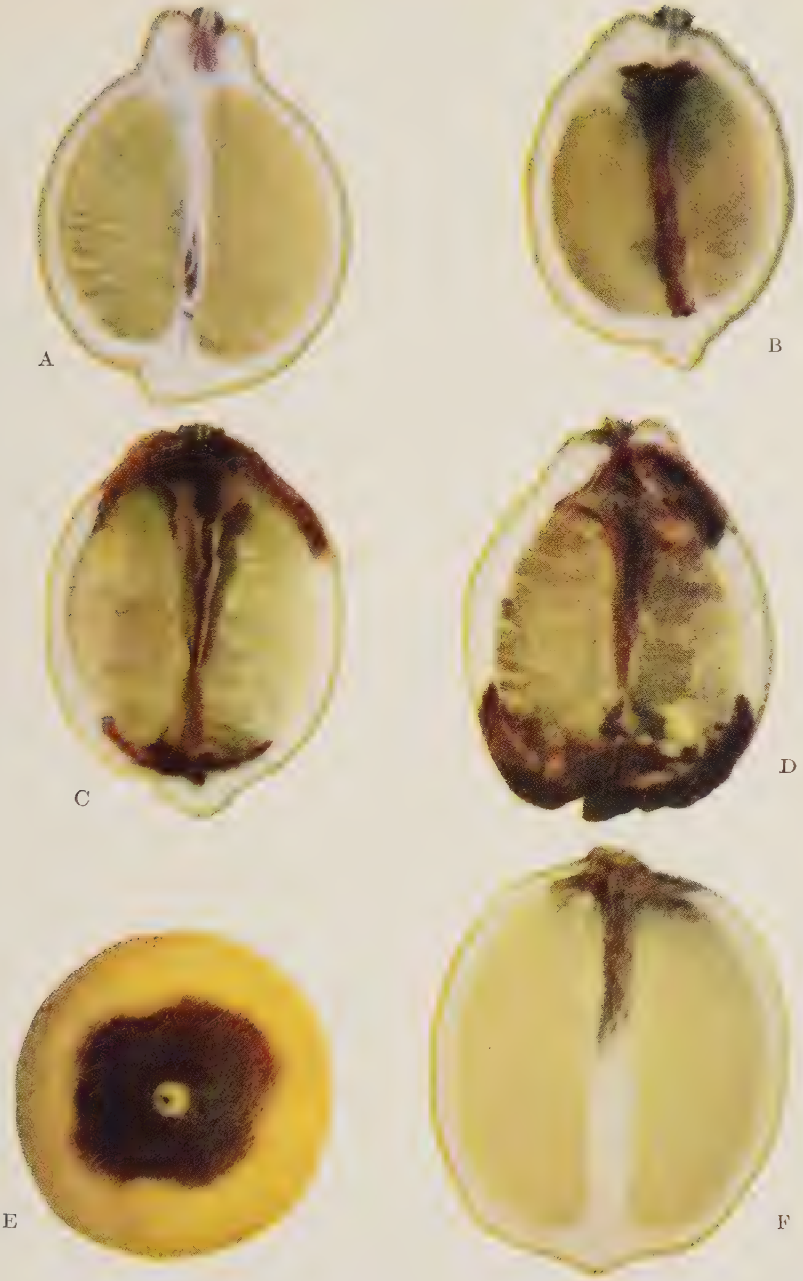

FIG. 130.—Alternaria rot and Pleospora rot in lemons, California. A to D, Different stages of Alternaria rot or "center rot." E and F, Pleospora rot or a firmer, drier type than the above. (*Photo for A to D contributed by E. T. Bartholomew.*)

(*Facing page* 390)

come through to the surface. The color of the interior takes on shades of brown to nearly black; in general, the colors approach Ridgway's (1912) cinnamon brown to Prout's brown, and where it breaks through on the surface at a later stage, olive brown or natal brown with a dark citrine margin.

A cinnamon-brown to Prout's-brown discoloration on the rind, advancing from the stem or stylar end, also frequently accompanies this disintegration of the central portion. During the initial stage, it can be detected only by cutting, but in medium or later stages, it may be detected by a soft pliable condition when pressed in the hand.

2. Frequently the Alternaria rot of lemons takes a somewhat different form, a more typical end rot. There is a gradual browning of the exterior as well as interior, starting at the button or more rarely at the stylar scar. It becomes, at first, leathery pliable, but soon quite soft pliable. In this form, it may advance only a little faster on the interior than on the exterior. The exterior colors are usually shades of brown, such as natal brown, mummy brown, olive brown, chestnut brown or carob brown with darker kinds that are iron gray to olivaceous black. This difference in character is possibly due to the interior tissue being stronger than in cases which take on the pure "center rot" form. It is thought to occur on less mature fruit or possibly (in the absence of internal decline), on fruits with other serious internal weaknesses.[1] It is also thought to be due in part to different strains or varieties of the Alternaria fungus.

The Causal Agent.—The agent in the actual disintegration and breakdown of the tissue is a fungus similar to *Alternaria citri* Pierce, first described in connection with a dry, black rot of navel oranges. There are, however, a number of strains or varieties of Alternaria associated with this type of decay in lemons, and their somewhat different growth reactions on certain culture media suggest that we may have strains differing also in their virulence (Fig. 132).

Certain species of Alternaria are known to have a perfect stage in Pleospora, and we have found in lemons strains that show a Pleospora stage in cultures. One of these has growth characteristics very distinct from the usual type of Alternaria in that it produces on corn meal and glucose potato agar only Pleospora perithecia with perfect spores but no Alternaria spores. This form has been found associated with a firm, dry end rot of lemons. By inoculation, it produces an entirely different type of rot, which we are calling Pleospora rot of lemons (p. 393). A technical description of *A. citri* Pierce will be found on page 396 under Black Rot of Oranges.

Contributing Conditions.—Abnormal conditions of the fruit tissues, such as those brought on by lack of moisture in soil and air, slight sunburn or frost injury, the presence of internal decline and membranous stain, high temperatures and age of fruit are thought to be the main factors favoring the Alternaria rot of lemons. It has been shown by the work of Bartholomew (1923*a*) that this form of decay is favored by the presence of internal decline and that the latter is partially related to moisture conditions of air and soil. Observations have repeatedly shown that old fruit held for a long time on the tree before picking or in storage after picking, or both, is most apt to have large percentages of this decay. It is also a common observation that the "tree-ripe" fruits tend to have more Alternaria rot in a given time than that when picked in the "green," "light green" or "silver" stage.

---

[1] For recent investigations regarding this disease see bulletin, soon to be published, in Cal. Agri. Exp. Sta. on *Alternaria rot of lemons* by E. T. Bartholomew.

That fairly high temperatures are also favorable to Alternaria rot was shown by Bartholomew's (1923) experiments in which in three and one-half months in storage the greatest percentage developed at 82 and 90°F. and a fairly high percentage even at 97°F. In this latter temperature, more fruits developed rot than at 59 or at 68°F. The temperature for the most rapid growth of the fungus mycelium in culture was about 77°F.

Control.—The measures suggested for control of Alternaria rot of lemons are indirect, having to do with producing sound, strong, resistant fruit, rather than direct, involving spraying or treatment at the packing house. The fungus is an ever-present one under most California conditions and becomes established in the tissues of the button or beneath it in the orchard. It is further indicated that the fungus is on or in the buttons at a very young stage (Bartholomew 1923*a*) and remains in a dormant or semidormant condition until the fruit becomes physiologically changed in maturing. Unfortunately, the fungus has not so far been successfully killed on the buttons by any of the commonly employed fungicides and disinfectants except at strengths injurious to the fruit.

Indirect methods for the prevention of serious losses from Alternaria rot may be listed as follows:

1. It has been shown that sound normal fruit is resistant to the decay. Proper fertilizing, irrigation, protection against wind, protection against too low air humidity, too low temperatures, insect injury, etc. would be expected, therefore, to minimize this type of decay.

2. Holding the fruit too long on the trees, especially the tree-ripe fruit, should be avoided.

3. Prolonged storage of weak fruit having slight frost damage internally or showing internal decline or membranous stain should also be avoided.

4. Fruit that is not physiologically strong should be eliminated as far as possible from shipments, especially in the hotter weather of summer and fall.

5. It is not yet known to what extent the hot-water borax treatment will control Alternaria rot, but on theoretical grounds it is believed that it will not prove of much value for this type of decay, which is initiated in the orchard and depends not so much on external injury as upon internal

weakness of the interior tissues. There is need for further research in this field.

PLEOSPORA ROT

In connection with a rather firm, hard rot of the fruit at the stem end, a species of Pleospora has been found which acts quite differently on lemon fruits from the Alternaria fungus. This was found as one of the minor rots occurring on fruits in storage or on arrival on the eastern markets in 1924 (Fawcett 1925*a*).

Symptoms.—This rot begins as a dark discoloration immediately around the stem end (Fig. 130E, F). Unlike most of the stem-end rots, the tissue at first remains quite firm, not leathery and pliable nor soft and easily punctured. As the spots develop to a considerable size, they may then become slightly leathery and pliable and very dark brown to almost black. When cut, the tissue is stained brown in the core and inner part of the rind.

Causal Agent.—The causal agent has been shown by inoculation experiments to be a species of Pleospora. Although the genus Pleospora is the perfect stage of certain species of Alternaria and Macrosporium, this Pleospora does not usually produce any imperfect spores in ordinary culture media in the laboratory. The mycelium usually remains a grayish color, and the black color, due to abundant formation of spores, as in *Alternaria citri*, is absent. The fungus readily produces the perfect stage of Pleospora after being grown for a short time on glucose potato agar. Inoculation experiments indicate that this fungus is capable of advancing into sound immature lemons after they are picked, much more quickly and readily than does the ordinary Alternaria of the *A. citri* type.

ALTERNARIA ROT OR BLACK ROT OF ORANGES

The so-called black rot of oranges, due to *A. citri* Pierce, is usually a firm, dry, slow form of decay very common in the stylar end of navel oranges in California, but occasionally found in other varieties. It may occur either in young green fruit, causing a certain amount of dropping, or in mature fruit. In lemon fruits, this dry form may sometimes occur, but is more likely to be replaced by an interior and softer breakdown, possibly due to other strains or species of Alternaria. These lemon forms of Alternaria decay are discussed under a separate heading in this Chapter.

History and Distribution.—The black rot was described by Pierce (1901, 1902), who had noted it as early as 1892. It is usually considered in California a minor disease of orange fruits, but may, in certain seasons and certain localities, assume considerable importance. It appears to be more prevalent in the warmer, drier sections, such as those of Arizona and the interior valleys of California, than in the moister, cooler sections near the coast. The same or similar rots in oranges have been reported in various countries: in Florida by Fawcett (1912*c*) and Burger (1923*a*), in Cuba by Johnston and Bruner (1918), in South Africa by Doidge (1924*a*), in Victoria, Australia, by Adams (1923). Lee (unpublished) found it of common occurrence in Valencia oranges shipped from California in the Chinese and Philippine markets. The fungus was discussed in connection with June drop of young navel oranges by Coit and Hodgson (1918). A related organism *Stemphyllum citri* was described in connection with what was designated as end rot in Arizona by Patterson and Charles (1910). The disease is referred to as causing a considerable loss from falling of fruit, but the symptoms are not described.

Symptoms.—The most characteristic outward symptom of black rot on oranges is premature coloring of full-sized or nearly full-sized fruit on the tree. The rot is most often noticed just before the normal crop colors. The infected fruits at this time color up sooner than the sound fruits and turn a deep-orange color. These often look sound on the exterior, but when cut have a dry, black decayed place within, at or near the stylar end (Fig. 131). The rot starts from spores which appear to get into imperfections at the navel and while the fruit is growing.

The structure of the navel orange furnishes an ideal condition for the black rot. As described by Coit and Hodgson (1918):

> It is really a double fruit with the secondary orange very small and variable in shape crowded into the apex of the primary fruit. The interior fruit is usually a little tardy in development, and frequently after the petals fall its style pushes up through the primary style, causing it to split and finally break away, leaving the pieces of its base wedged in between the two oranges. These remnants may or may not be overgrown with sound tissue. Infection occurs during blossom, the spores being deposited on the stigma either by wind or insects, and as the style dies the fungus grows down to the very base as was shown by cultures. The pieces of old style left wedged in between the two oranges are, therefore, infected with Alternaria. The depth and position of these pieces vary widely as the size, shape and proliferations of the navel vary.

The dry decay on the interior of oranges is usually mummy brown to almost black, and proceeds very slowly in sound tissue. Sometimes young green navel oranges exude gum at the navel cavity and turn yellow and drop off while still small. The cells of the pulp sacks are slowly penetrated and destroyed. At first, the peel is not affected, but later as the mycelium extends, it may reach the peel and cause it to become discolored over the affected interior. It is usually confined to a limited portion near the end and usually to one side of the navel end.

Causal Agent.—The cause of black rot is the fungus *Alternaria citri*, whose spores (Fig. 132) are believed to gain entrance to the stylar end of navel oranges while the fruit is still young. The mycelium may also enter later by means of imperfections. It may also sometimes enter imperfections at the stylar end of other varieties of orange. This fungus was first described by Pierce (1902) as follows:

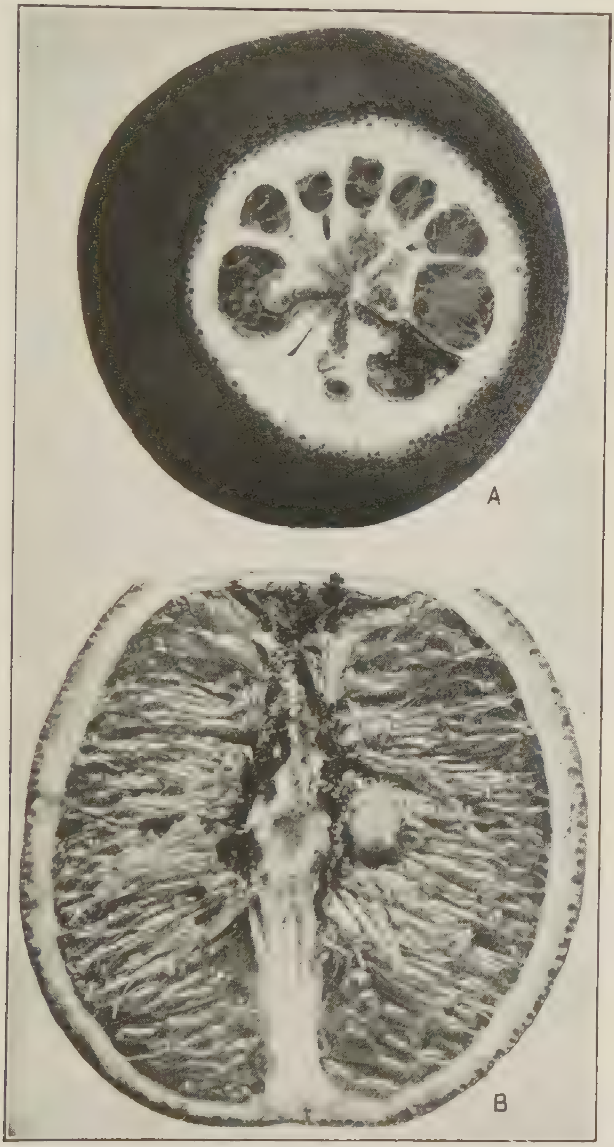

Fig. 131.—A, Alternaria rot or black rot of oranges due to *Alternaria citri*. Mature Washington Navel orange with navel-end cut across to show black rot in some of the segments. (*Cal. Exp. Sta.*). B, California-grown Valencia orange from Manila market showing development of Alternaria rot along the core. (*Photo by H. A. Lee.*)

Alternaria citri.—In oranges in California. Effused, olivaceous, becoming nearly black. Mycelium abundant, loosely interwoven, gray, consisting of slender, septate, yellowish or olivaceous-hyaline threads, penetrating and overrunning the matrix, much branched, the branches mostly a little swollen at the apex and bearing the terminal variously shaped conidia, which are obovate, oblong-elliptical or subglobose at first, 10 to 22 by 8 to 15μ in diameter, and mostly three-septate, finally large, 25 to 40 by 15 to 25μ, short, clavate, oblong, four to six-septate and slightly constricted at the septa, the cells divided by one or more longitudinal septa, dark olive brown. The conidia are oftener three to six-catenulate in series, either simple or branched. As shown by cultures, secondary conidia often arise directly from the primary, thus giving rise to a secondary series. (Spores like those of Fig. 132 measured 20 to 28 by 8 to 24μ.)

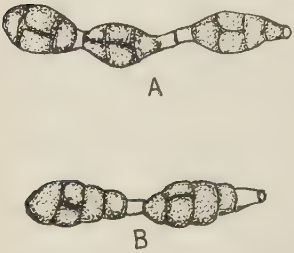

Fig. 132.—*Alternaria citri.* Parts of chains containing spores produced on glucose potato agar. A, from isolation from black rot of Washington Navel orange; B, from isolation from Alternaria rot of lemons. The size and shape of spores vary greatly in each case. These average sized spores are shown not as indicating any constant difference between the strains in lemon and orange, but as showing the general type of spores in the Alternaria rot fungus. Magnified about 600 diameters.

Control.—Growers and others have reported from time to time beneficial results of fungicidal spraying for black rot. Recent experiments by Barrett and Blatt in California have shown, however, only negative results from spraying with lime sulfur or Bordeaux mixture, even though this was carried out at frequent intervals beginning during the blossoming period. The black rot of oranges is not, as a rule, considered of sufficient importance to call for preventive measures, although exceptional cases or seasons have been reported where a high percentage of navel oranges was affected; in northern California, as high as 50 per cent (Fawcett 1922*c*) were found affected, and in Florida (Burger 1923*a*), during a summer season of extreme rainy weather, as high as 5 to 25 per cent of other varieties were found affected. In the packing house, it becomes necessary to cull out as far as possible all oranges with Alternaria rot in them, as these break down in transit and on arrival at the markets. While Alternaria rot of oranges in itself is a slow decay, it usually opens up the way for green and blue mold.

ANTHRACNOSE ROT

The anthracnose fungus, *Colletotrichum glœosporioides*, may under certain conditions produce a soft, pliable rot usually in very mature, old, overripe fruit. Most of the strains of the anthracnose fungus are unable to cause rotting in strong, fresh, vigorous fruit.[1] The anthracnose rot is not easily distinguished on lemons or oranges from certain types of Alternaria rot and Fusarium rot. Anthracnose decay has been readily produced on mature fruits by inoculation in the laboratory.

---

[1] Recently, a strain of this fungus was found advancing from twigs into the stem ends of apparently normal tangerine fruits in California, while they were still attached to the tree. A mummy-brown firm rot is produced.

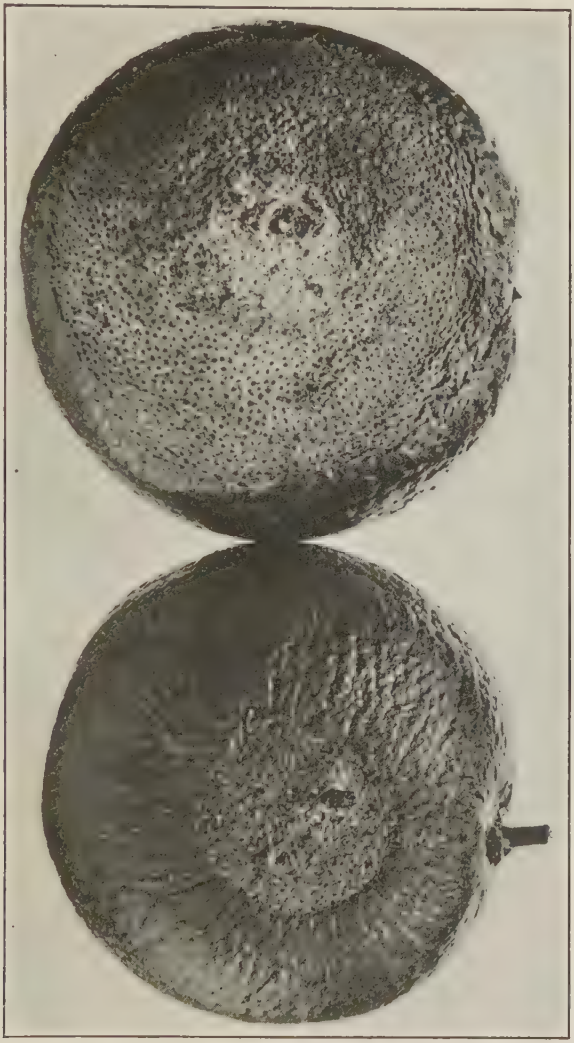

Fig. 133.—Decay in orange from the anthracnose fungus *Colletotrichum gloeosporioides* following punctures from the Tortrix worm, *T. citrina*, California. About natural size. (*After Quayle* (1911).)

Symptoms.—Anthracnose as a distinct rot, in contrast to the hard, firm anthracnose spot of the surface, most often develops through the stem end. It may occasionally develop from an anthracnose spot on the rind inwardly (Fig. 133). At first, it is evidenced by firm to semipliable, small brown areas around the "button" or stem end. Later, as the area enlarges, a soft, pliable rot develops which may be dark brown in color (Mars brown, cinnamon brown, or even mummy brown per Ridgway 1912). Very slowly developing spots may become sepia to black in color (Fig. 134). The decay slowly advances along the core, inner rind and pulp. The interior discoloration may be snuff brown, bister to nearly black in different cases, with mycelium sometimes giving a buff pink to the pulp that has lost its juice. The characteristics of the causal fungus are discussed on page 289.

The contributing conditions and control are about the same as those discussed for Alternaria rot (p. 391).

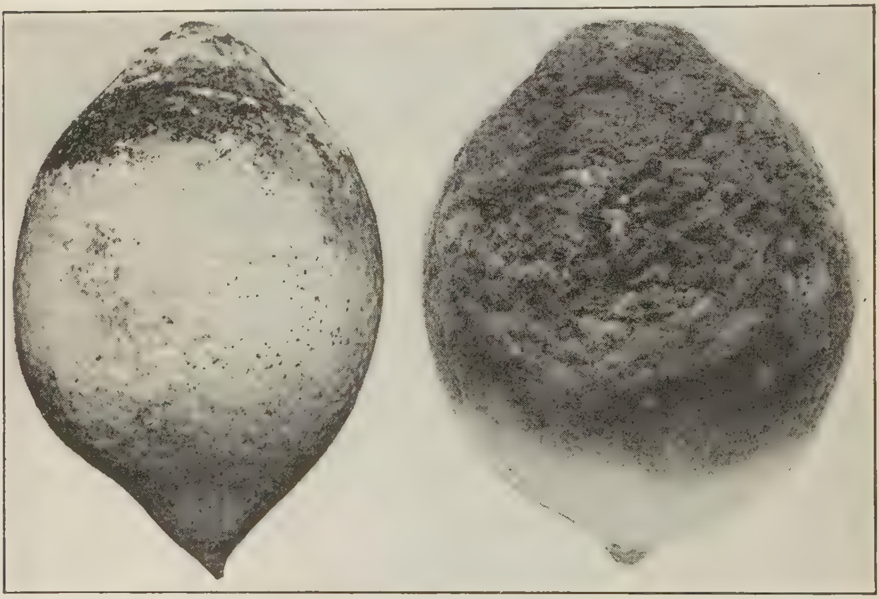

Fig. 134.—Anthracnose rot of lemon fruits advancing from the stem end, California. (*Photo by C. O. Smith and J. T. Barrett.*)

FUSARIUM ROT

Species of fungi belonging to the genus Fusarium may produce decay under certain conditions in both oranges and lemons. The decay usually develops quite slowly and is similar in most cases to that produced either by the Anthracnose or the Alternaria fungus. Species of Fusarium may also frequently occur on decaying fruits in association with other fungi.

History and Distribution.—We have, in past years, both in Florida and California, met with this decay in Citrus fruits, but it has never appeared to be anything but a minor form. In Porto Rico, Stevenson (1918*e*) mentions a pink stylar-end rot associated with Fusarium, in addition to the brown or black one due to Alternaria. Boncquet (1922) reports a Fusarium in navel oranges found in connection with June drop. In past years we have isolated Fusarium in a few instances from the navel cavity of half-grown oranges, but in our experience Fusarium in navel oranges appears to be of rare occurrence in California as compared with the Alternaria fungus.

Fusarium has also been isolated occasionally from rotting oranges and lemons in storage. While making an investigation of decay in Citrus fruits from California in 1924, we isolated Fusarium occasionally, especially from decayed lemon fruits that had been picked a long time (Fawcett 1925*a*).

Inoculation experiments with cultures of these fungi have shown that a decay may be produced after many weeks. Other strains of Fusarium identified as *F. solani* and *F. lateritium*,[1] isolated from roots and fruit, respectively, of sweet orange, produced a very slow decay on mature orange fruits. Plakidas (1925), experimenting with three species of Fusarium (*F. solani*, *F. asclerotium* and *F. perinum*) isolated from peach fruits, produced decay with these fungi through injuries in orange fruits in twenty to thirty days. Lemon fruits were not affected.

Symptoms.—The Fusarium rot usually begins at the stem end of the fruit, although it may sometimes start at the stylar end or in wounds on the side. The decay varies from a semipliable form somewhat resembling the later stages of anthracnose rot to almost a soft rot. It may sometimes become nearly as soft as the Alternaria rot of lemons. The color is also variable but is usually light brown to dark brown on the outside and light brown on the inside. The Ridgway colors vary between mummy brown and Prout's brown. The contributing conditions and control would probably be the same as that for anthracnose rot.

STYLAR-END ROT OF PERSIAN LIMES

At the outer or stylar end of Persian limes and sometimes lemons, a firm, light-colored collapse of tissue of the rind takes place. This stylar-end rot has been reported in Cuba by Earle and Rogers (1915) and in Florida and California by Fawcett (1915*a*). The areas are fairly dry and firm. They start as a whitish to drab-colored sunken patch at the base of "nipple" or tip and progress till about one-half of the fruit is involved. The color as the spots are well developed is light drab to drab (Ridgway 1912). The area remains firm with a water-soaked appearance (Fig. 135). There is sometimes a partial break down within the fruit, with white spots which appear to be composed of hesperidin crystals.

Cause Unknown.—It is probably a physiological breaking down of the rind to which the Persian lime appears to be especially subject, followed and emphasized by the entrance of organisms. The anthracnose fungus has been found in the spots under Florida and Cuban conditions, but this is probably a secondary agency in producing the decay. This fungus was not found on fruits with similar lesions in California.

---

[1] We are indebted to C. D. Sherbakoff for identification of these species.

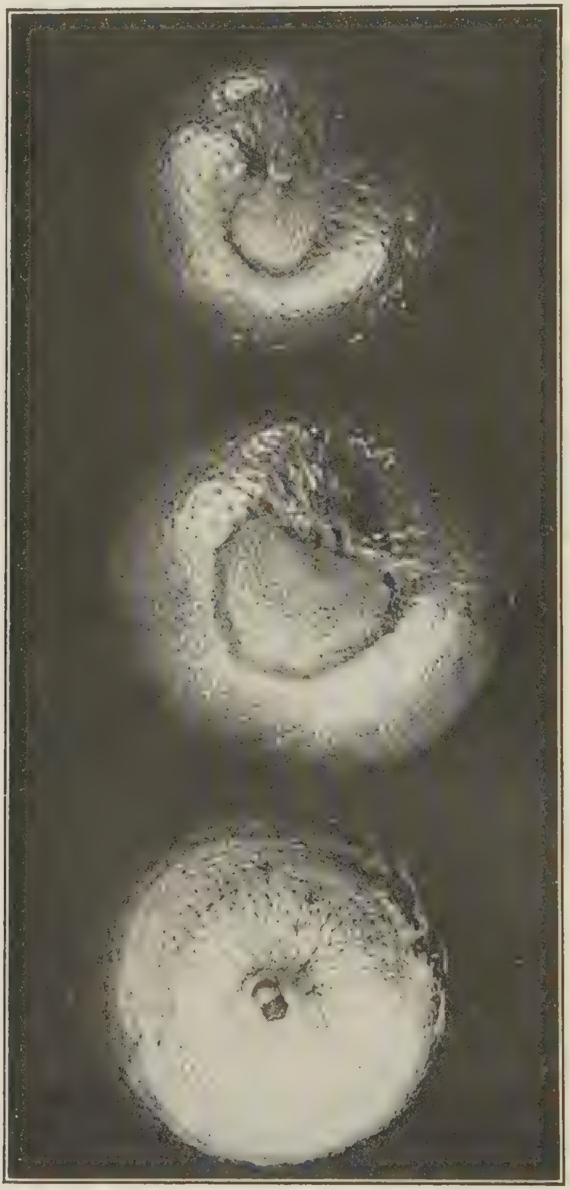

Fig. 135.—Stylar-end rot of Persian limes, California. (*Photo by C. O. Smith.*)

Part of the loss from this disease can be avoided by picking the fruit before it has become too mature.

PHOMOPSIS STEM-END ROT

Several species of Phomopsis fungi are capable of producing pliable, leathery stem-end rots usually beginning at the "button" or cut stem end. These are generally known as stem-end rots. This stem-end rot first attracted attention in Florida, where frequently serious losses result from the decay of oranges and grapefruit, both in the orchard and in transit. The same or a similar rot has since been reported in various Citrus countries.

History and Distribution.—Stem-end rot due to *Phompsis citri* Faw. was first reported and studied in Florida by Fawcett (1910*c*, 1911*a*, 1912*b*). The same fungus was found to be responsible for the killing of twigs (p. 288) and a minor form of gummosis (p. 228). This stem-end rot received further investigation in Florida by Burger (1923*a*, *b*) and by Winston, Fulton, and Bowman (1923). The same fungus was also found by Stevens (1912) to be the causal agent in melanose (see p. 226). Phomopsis stem-end rots of a similar kind have since been reported in Porto Rico and Cuba, but their seriousness is probably not so great in these islands. An end rot similar in effect but due to a different fungus, Diplodia, appears to be more important there. A Phomopsis stem-end rot due to a different species has in recent years been found in California lemon fruits. It has not been found naturally in California oranges, although when used artificially in the laboratory, the fungus appears to be capable of infecting oranges, if kept for many weeks in storage. Attention was first called to this California form by Burger (1920*a*) who found it in 1918 in fruit on the eastern markets. It was later studied by Fawcett (1922*b*), who found it to be different from *P. citri* in virulence and growth characteristics and who described it as *P. californica.* This species has since been shown to be the causal agent in decorticosis or shell bark of lemon trunks (Fawcett 1924). A recent investigation of decay of lemon fruits in storage in the packing houses and in the eastern markets has revealed that weak lemon fruits from various sections of southern California may sometimes show this type of decay. Examination of lemon fruits from Sicily also showed stem-end rot from which pure cultures of a Phomopsis fungus were obtained, most of which more nearly resemble the *P. californica* than *P. citri*. It appears to be intermediate between the two and is probably *P. cytosporella* (Penz.). Horne (1922) found another Phomopsis stem-end rot on grapefruit from the Isle of Pines and described it as *P. caribaea.* We are indebted to P. H. Rolfs for the information that stem-end rot and melanose are common in certain parts of Brazil.

Symptoms.—The main external characteristic of all the Phomopsis stem-end rots is a leathery, pliable area encircling the "button" or stem end, buff colored to brown in color. These, however, in their initial stages cannot with certainty be distinguished without pure culture tests from end rots due to species of Diplodia and Dothiorella. In later stages, however, they often develop distinguishing characteristics that make it possible to separate Phomopsis from Diplodia and Dothiorella rot.

Phomopsis Stem-end Rot of Florida.—Since this is of importance especially on oranges and grapefruit in Florida, its characteristics on these fruits will first be described. The appearance varies somewhat according to the maturity of the fruit, the temperature at which it takes place and the amount of moisture present. As a decay of mature packed fruit, its first symptoms can be detected only by a pressure of the finger, which reveals a slight leathery pliableness. Soon a very slight "off color" is seen with shades of brown or drab appearing. As the area enlarges to occupy one-third to one-half the surface, the color becomes dull brown to darker drab brown and more pliable. The peel remains pliable, not soft nor easily punctured by pressure of the finger. On grapefruit on the markets, the color may be honey colored to ochraceous buff at first, gradually merging into the natural buff yellow or pinard yellow (Ridgway 1912) of the surface. Later, it becomes about the same color as it does on the orange. If the fruit is opened, the decay will be seen to have advanced most rapidly along the center where the segments join, and along the inner white part of the rind, and not so rapidly in the juice sacks (Figs. 136C, D and 137). In the orchard, the earliest visible appearance on immature fruit is a dark-brown, reddish-brown to almost black discoloration about the stem end. Orange and grapefruit tend to drop off before discoloration is marked, but tangerine oranges may cling to the tree while still affected.

Phomopsis Stem-end Rot of Isle of Pines Grapefruit.—A tan-colored stem-end rot in a shipment of grapefruit from the Isle of Pines, Cuban territory, has been briefly reported by Horne (1922). In character of development, it is probably quite similar to the Florida type. The fungus was described as a new species, *P. caribaea* Horne. So far as known, this rot has not since been reported.

Phomopsis Stem-end Rot in California.—In California, Phomopsis stem-end rot, due to *P. californica*, has been found only on lemon fruits and more especially in the coastal regions. It has been seen rarely in the orchard, but under certain conditions becomes a minor form of decay in the lemon storage houses and during transportation.

The symptom are similar to that of the stem-end rot in Florida. A pliable, leathery decay proceeds usually from the button or stem end. Its first symptom is merely a pliable condition at the button without visible discoloration. Later, as the area enlarges, it becomes more

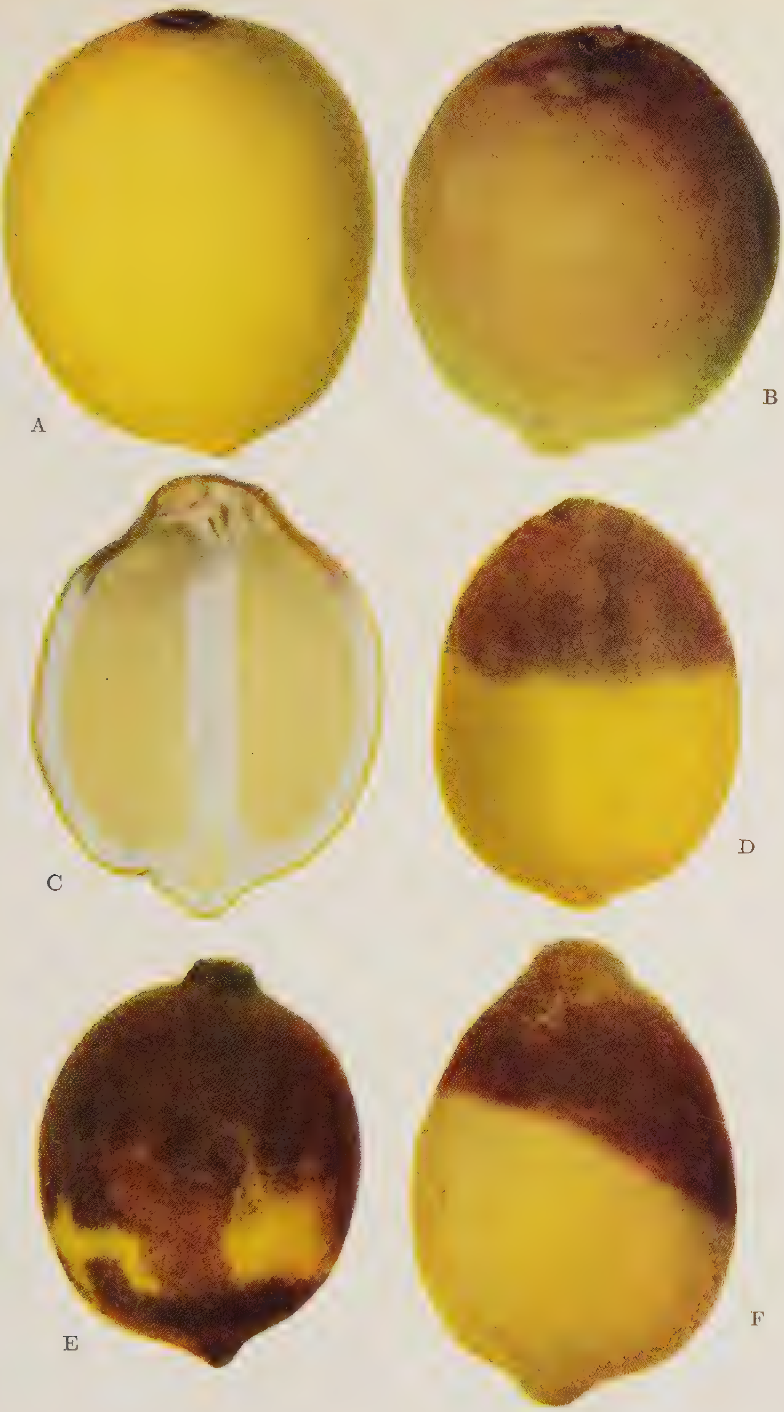

FIG. 136.—Phomopsis stem-end rots and Trichoderma rot. A, Sound lemon ready for packing, California. B, Phomopsis stem-end rot of California due to *Phomopsis californica*. C and D, Phomopsis stem-end rot of Florida due to *P. citri*. E and F, Trichoderma rot, due to *Trichoderma lignorum* (see also Fig. 112E). About two-thirds natural size.

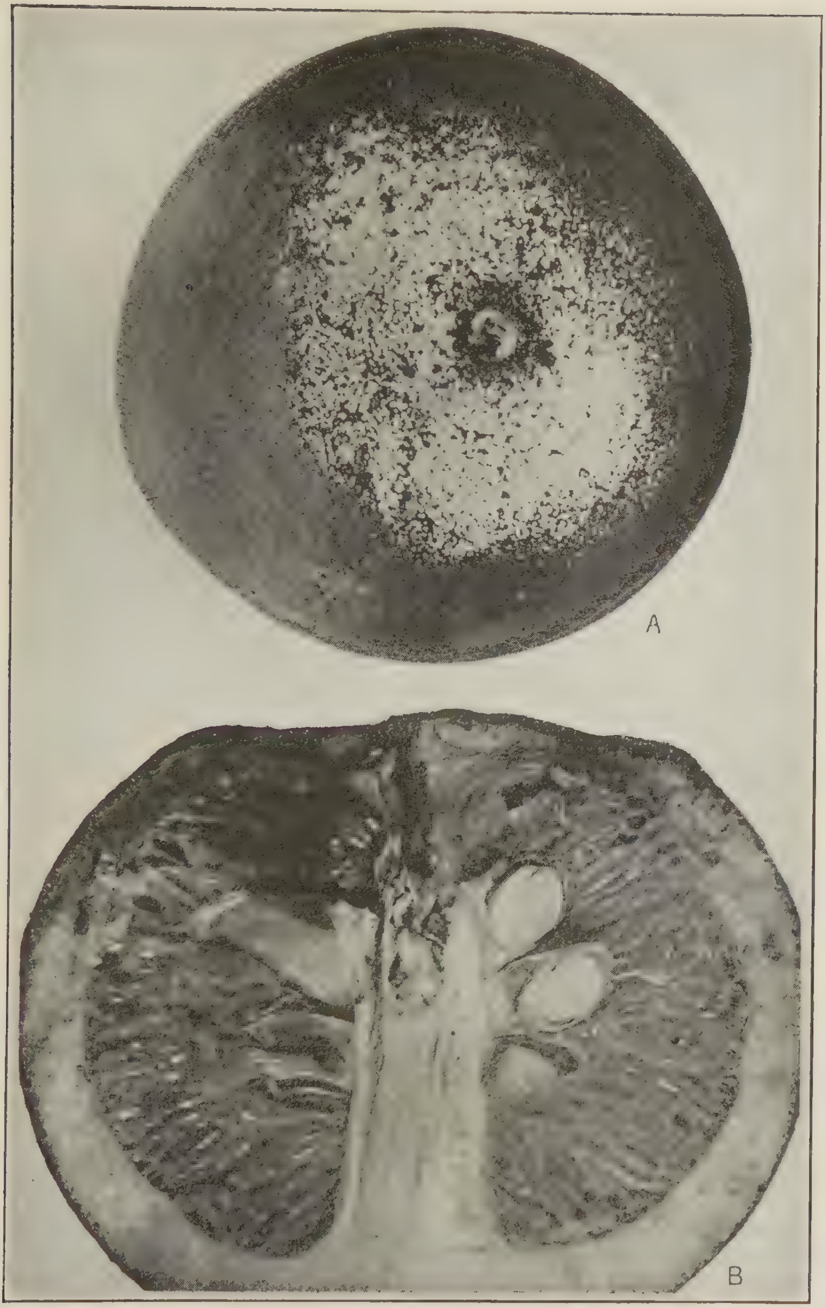

FIG. 137.—Grapefruits rotted by the stem-end rot fungus *Phomopsis citri*. A, tufts of white mycelium developing in a very moist atmosphere. These rarely occur under natural conditions. B, section of grapefruit showing Phomopsis stem-end rot advancing from the stem-end. Florida.

pliable and the natural color of the yellow fruit changes first to an antimony yellow, honey yellow, then through ochraceous yellow, Isabelle color, ochraceous buff to buffy brown (Fig. 136B). The color is distinctly lighter, as a rule, than that due to the Florida Phomopsis or even the Italian form, as shown by inoculations on lemons, in the laboratory under the same conditions. Internally, the tissue becomes water soaked but does not discolor or darken so rapidly as in the other forms or in Diplodia and Dothiorella rots.

Phomopsis Stem-end Rot of Italian Lemons.—The pliability and manner of development, of the stem-end decay found in Italian lemons in storage on the eastern markets were the same as in California fruit, but this decay is, as a rule, darker in color than that on California lemons. The color on the surface when well developed was greenish brown to dark brown (dresden brown, Prout's brown to mummy brown). Inside, it developed a dark discoloration, buff brown (Prout's brown) to almost black in some cases. The characteristic of the fungus causing it was found to be intermediate between the Florida and California species of Phomopsis, when grown on culture media, but resembled the California forms more than the other. It is probably *Phomopsis cytosporella* (Penz).

Causal Fungi.—Several species of Phomopsis[1] cause a similar type of leathery, pliable stem-end decay. They all live a saprophytic existence in the orchard most of the time, but are capable of entering the fruit from the button while still on the tree or of entering the cut end and breaking down the tissue with varying degrees of rapidity, depending on conditions of the fruit as well as the species or strain of the fungus. Most of them have been observed commonly fruiting on dead twigs or bark in Citrus trees. One of them, *Phomopsis citri*, has been shown to be also the cause of melanose and a minor form of gummosis (p. 228), and another, *P. californica*, has been found associated with decorticosis (p. 176). Their characteristics are as follows:

Phomopsis citri.—This fungus is found commonly on dead twigs on dead bark of Citrus trees in Florida. The spurs from which infected fruit has dropped frequently die back a distance of 3 to 12 inches or more and aften show small drops of gum near the junction of dead and live wood. The fruiting bodies (pycnidia) and spores of this fungus are found in abundance on these dead branches. Rarely are they produced on the fruit, as shown in Fig. 138. On dead twigs, very minute, black, flask-shaped bodies (pycnidia) are found partially buried in the surface tissue with their rounded tops breaking through the epidermis[1] (Fig. 139A). In moist weather, at certain times of the year, yellowish globular masses of spores ooze out through openings in the top (ostiole) from these pycnidia. The fungus has been described by Fawcett (1912*b*) as follows:

---

[1] Several of these so-called species on Citrus are similar morphologically, though they appear to differ greatly in their degree of virulence, especially *P. citri* and *P. californica*. The strains isolated from Italian lemons stored in the eastern markets in 1924 appeared more nearly like *P. californica* than like *P. citri* in virulence, but appeared to be intermediate in growth characteristics. Many recent isolations from California lemon fruits and from bark affected with decorticosis have given strains differing somewhat among themselves in growth characteristics. It is predicted that further study may show that morphologically *P. californica* is not distinct from certain Italian forms nor perhaps even from *P. citri*.

Pycnidia scattered, ovoid, parenchymatous, green or dark colored, 200 to 450μ diameter, erumpent, thick walled, top easily broken away leaving spores exposed (Fig. 139A). Ostiole 35 to 45μ in diameter. Spores ovate or fusiform, often flattened on one side, hyaline, often one to three guttulate, 5 to 9 by 2.5 to 4μ mostly 6 to 8 by 3. Basidia 1.5 by 12 to 15μ. Paraphyses 20 to 30 by 0.75 to 1.5, easily detached, often curved at one end (Fig. 139B, C). On dead branches and decayed fruits of Citrus in Florida, United States of America.

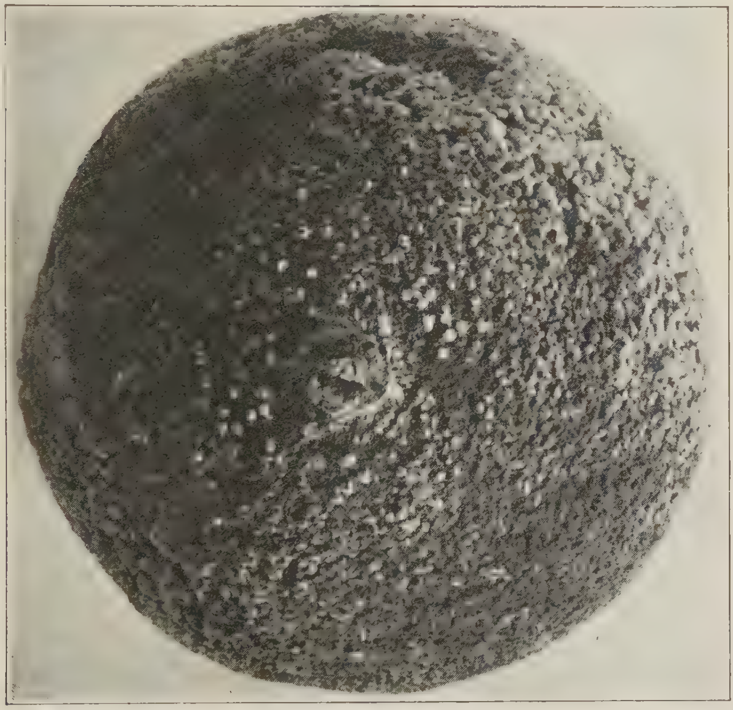

FIG. 138.—Immature orange rotted by the fungus *Phomopsis citri*, showing spore-bearing bodies (pycnidia) which have developed under moist conditions in the laboratory. About one and one-half times natural size. Florida.

On culture media, such as standard nutrient glucose agar, prune or orange juice, the mycelial growth is chalky white forming rather compact mats (Fig. 141A, B). Pycnidia form readily when the fungus is transferred to large sterilized orange stems.

---

[1] The perfect stage of this fungus, a Diaporthe, has recently been discovered by W. A. Wolf. (In press, Jour. Agri. Res. U. S. D. A.)

Phomopsis caribæa.—This fungus isolated from Isle of Pines fruit was shown by Horne (1922) to be capable of producing a stem-end rot of grapefruit. Its characteristics are described as follows:

> On sterilized orange twigs, a white, matted, cottony mycelium forms in which numerous small conical pycnidia become evenly scattered over the surface. They are white to yellowish and smoky brown. Spores were 5.6 to 8 by 2.2 to 3μ, scolecospores were 20 to 32 by 1μ (Fig. 140). Horne states that growth in nutrient agar differs from that of *P. citri* in being more vigorous and retaining its filamentous aspect, not becoming finely granular or limelike.

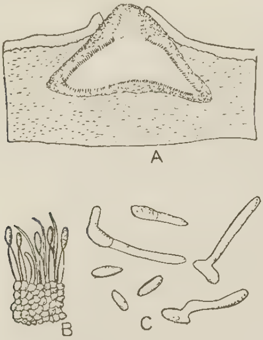

FIG. 139.

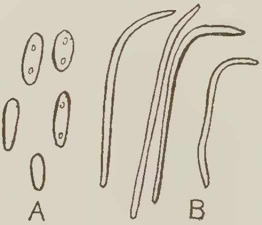

FIG. 140.

FIG. 139.—Pycnidium and spores of the stem-end rot fungus *Phomopsis citri:* A, diagrammatic section of a spore-bearing body (pycnidium) breaking through the epidermis of the bark of orange branch, ×40; B, portion of the wall of the pycnidium showing arrangement of spores and scole cospores, ×500; C, spores germinating in dilute prune juice.

FIG. 140.—*Phomopsis caribaea:* A, spores from pycnidia; B, scolecospores from the same pycnidia grown in cultures. ×750. (*After Horne* (1922).)

Phomopsis californica.—This fungus is also found fruiting in dead twigs on the tree and especially on the surface of dead strips of bark in connection with decorticosis (Fawcett 1922*b*, 1924) (see also p. 180). The fungus was first found in connection with stem-end rot on the eastern markets by Burger (1920*a*) and later was found to be a minor decay in orchard and packing houses. The fungus is described by Fawcett (1922*b*) as follows:

> Pycnidia mostly clustered, sometimes rarely scattered, ovoid to conical, dark colored, 160 to 300μ in diameter, erumpent. Ostiole 25 to 35μ in diameter. Spores ovate, mostly rounded at both ends, sometimes nearly acute at one end, hyaline. Mean size of 100 spores measured 8.4 ± 0.7μ long and 3.9 ± 0.5μ wide. Range 7.7 to 9.1 by 3.4 to 4.3μ. Basidia about 15μ long, paraphyses (scolecospores) 22 to 0.3 by 1.6μ curved at one end. Differs distinctly from *P. citri* in coarser hyphæ with tendency to form strands or fans of growth (Fig. 141C, D), the hyphæ becoming cinnamon brown instead of pure white when in contact with glucose potato agar; also differs by forming principally paraphyses instead of spores on above media. On dead outer bark and on decaying fruits of *Citrus limonia* in California, United States of America.

This fungus is similar in many respects to *P. citri*, which causes melanose and stem end rot in Florida (see Chaps. XI, XVIII). *P. californica* is readily distinguished from the latter, however, in pure cultures: (1) by a coarser growth with tendency to form strands or fans on glucose potato agar plates (Fig. 141) and to become tawny to cinnamon brown with age, and (2) by pycnidia filled with scolecospores rather than true spores. *P. californica* also has a somewhat different temperature range and grows less readily at 27 to 30.5°C. than the other (Fig. 141). Recent study and isolation tests of fungi from stem-end decay on the markets have shown that there are a number of strains of this fungus in California differing slightly from each other in growth characteristics on culture media.

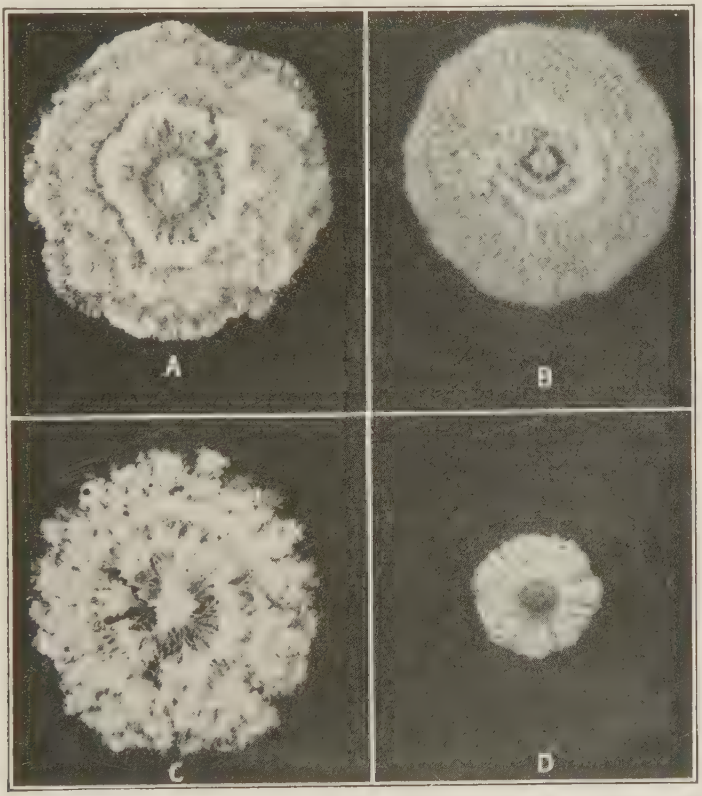

Fig. 141.—A and B, growth of mycelium of the Florida stem-end rot fungus, *Phomopsis citri*, in soluble starch agar in 10 days: A, at 76.1°F. (24.5°C.); B, (at 80.6°F. (27°C.). C and D, growth of mycelium of the California stem-end rot fungus, *Phomopsis californica* in soluble starch agar in 10 days: C, at 76.1°F. (24.5°C.); D, at 80.6°F. (27°C.). Natural size.

Phomopsis cytosporella.—This fungus, originally described by Penzig (1887) as *Phoma cytosporella*, might be, as judged from description and figures, the same as that found in Italian lemons in the eastern markets.

The basidia as recorded by Penzig are 20 to 30 by 2 to 2.5μ. Spores are hyaline, two-guttulate, 7 to 9 by 2.5 to 4. It was found on the dead wood of lemon trees. The spores in the cultures we obtained from Italian lemon in the eastern markets on glucose potato agar appear to be slightly smaller and more slender than those of *P. californica* under the same conditions.

Contributing Conditions.—Although one of these species of Phomopsis in known to attack immature fruit at the stem end during certain seasons, they all, as a rule, break down mature or weak fruit much more readily and rapidly than immature or strong fruit. Some of the contributing factors in the orchard are probably, therefore, connected indirectly with factors that fail to make strong resistant fruit and more directly with conditions of temperature, humidity, presence of dead twigs, scale insects, physiology of the tree, etc.

In Florida, periods of unusually warm weather after the fruit begins to mature appear to have a tendency to increase the amount and hasten the development of this decay. The greatest loss, as a rule, other conditions being equal, occurs in orchards that are rather moist and shady, although it occurs under varying conditions of moisture or shade. The presence of an abundance of scale insects may also contribute to weakness of the fruit and its susceptibility in some cases. It has been pointed out by Burger (1923) that the time of partial abscission of the fruit while it is still on the tree is an important factor in infection. A period occurs in the life of the fruit when a ring of tissue at the stem end is separated, while the central portion of the stem containing the vessels remains firmly attached. It is at this period that infection is thought to take place. While infection may take place after the fruit is picked, it is likely that under commercial conditions most of it starts from spores or quiescent hyphæ already started while the fruit is on the tree. In the California Phomopsis, the stem-end rot of lemons appears to be most prevalent in the moister localities near the coast. It is also thought that most of the factors making for weaker fruit discussed under Alternaria rot are, to a certain extent, favorable also to this rot.

Control.—The prevention of losses from Phomopsis stem-end rot will need to begin for the most part in the orchard, but certain methods may also cut down part of the losses in packing house and market. The control measures for Florida stem-end rot on orange and grapefruit (which also includes Diplodia rot) is in part summarized by Winston, Fulton and Bowman (1923) in the following:

> Prune the trees and remove deadwood, in so far as good orchard practice requires. Spray the young fruit once or twice with 3-3-50 Bordeaux mixture plus 1 per cent oil as emulsion during April or certainly before May 5, as may be required for good melanose control. Keep the fruit at low temperatures, preferably between 40 and 45°F., and shorten as much as possible the time between picking and ultimate consumption.

For California conditions, where no losses from melanose occur and where the decay is a minor one and only on lemons, such spraying will probably not be commercially profitable, and if fumigation follows, Bordeaux will produce greater injury than benefit from consequent spotting and defoliation. Fulton and Bowman (1924) report considerable benefit from the use of borax solution (see p. 362).

DIPLODIA ROT

This form of decay begins, as a rule, at the stem end, but may also start at the stylar end or at definite injuries. It resembles Phomopsis stem-end rot and Dothiorella rot in being a leathery, pliable decay and cannot easily be distinguished from them in its earlier stages. It is most often met with in storage and transportation, but may also be found, to a limited extent, in the orchard.

History and Distribution.—A Diplodia rot due to the fungus *Diplodia natalensis* was first studied and described by Evans (1910) as a decay of lemon fruits in Natal, South Africa, and the causal fungus was also found capable of rotting all varieties of Citrus fruits. The same or a similar rot was studied on oranges and grapefruit by Fawcett (1911*a*, 1912*c*, 1913*a*) in Florida, where this decay is an important source of loss along with Phomopsis stem-end rot. The same or similar fungus was also isolated at that time from oranges shipped from Porto Rico (Fawcett 1913*a*). Later this was reported as important in Cuba (Earle and Rogers 1915, Johnston and Brunnier 1918), in Porto Rico (Matz 1917, Stevenson 1918) and in other West Indian islands on lime fruits (Nowell 1923). A similar Diplodia rot of less importance has been reported on lemons in California (Fawcett 1925*a*).

A Diplodia rot also occurs in the Philippines, in storage and in transit (Reinking 1921), the identity of which is as yet undetermined. Mandarin oranges are the most commonly affected, although sweet oranges, lemons and pummelos can be inoculated and the disease produced on such hosts artificially. This rot was never observed on green, hard young fruits but occurred only on mature specimens.

The causal fungus, a Diplodia, was isolated from affected fruits by Gaudencio Reyes, a student of the University of the Philippines, and successfully reinoculated into healthy fruits reproducing the disease.

Although species of Diplodia fungus have been described on Citrus, especially twigs or dead parts, in nearly every country where Citrus is grown Diplodia rots of importance have not so far as known been reported outside of those mentioned. This rot is similar in its early stages to Phomopsis stem-end rot (p. 401) and to Dothiorella end rot (p. 412).

Symptoms.—There is, at first, an almost imperceptible discoloration around the button with a slight abnormal degree of pliability, soon followed by a leathery, pliable condition and a drab to brown, translucent, watery discoloration of the surface of the rind. On lemons, the first color may be honey yellow to honey brown (Ridgway's honey yellow to Isabelle color). Later, the colors may change through cinnamon brown, dull brown to dark snuff brown (cinnamon brown, Saccardo umber to bister). The decay usually becomes darker, both externally and internally, and develops more rapidly than that of Phomopsis. On oranges, as it develops rapidly, it shows wide bands on the surface corresponding to the divisions of the segments within (Fig. 142A–D). It often advances on oranges or grapefruit quickly through to the stylar end, where a patch shows on the surface before all the peel is involved. It may also start in punctures, worm holes or other injuries perhaps more readily than that of Phomopsis. It is usually accompanied by exudation of a considerable amount of an amber-colored, sticky juice, a characteristic more frequent than with Phomopsis stem-end rot. As the entire fruit is involved, Diplodia rot on oranges becomes dark olive green to black, this color starting around the stem and then spreading over the entire surface. One of the California species of Diplodia produces a dark lavender to slate-violet color inside.[1] The fruit becomes pliable and is later a mummified black mass with a wrinkled, shriveled surface. If in a dry atmosphere, the fruit thus affected will dry out, as described by Evans (1910), to a hard body with the interior becoming a dark fibrous mass of tissue. If the fruit is kept in a moist atmosphere, the surface will soon show tufts of hyphæ, at first grayish olive, finally turning darker and completely covering the surface with a dark felt-like mycelial growth. It usually has a stronger odor of decay than Phomopsis stem-end rot.

In the Diplodia rot found in the Philippines on mandarin oranges, the rind turns dark brown, shrivels and becomes softer than the normal rind. Black pustules appear in the center of the dark-brown area, which are the fruiting bodies of the causal fungus. The inner tissues of the fruit are also affected and become a blackened mass.

Causal Agent.—Diplodia rot is due to the fungus, *Diplodia natalensis* Evans, or to species probably closely related. This fungus was originally described in connection with a decay of lemon fruits in South Africa (Evans 1910). The same or similar species of Diplodia produces the same type of decay in Florida, Cuba, Porto Rico, California and the Philippines. The pycnidia are usually abundant on dead twigs or bark of Citrus trees from which abundant spores may be washed or blown to the fruits.

These Diplodiæ on most culture media grow rapidly. at first producing a light or grayish mycelium, later turning dark or almost black. *D. natalensis* was described by Evans as follows: "Pycnidia scattered, at first covered by epidermis, afterwards

---

[1] A second very small, spored Diplodia has also been found in California capable of producing a firm, dry end rot on lemons, sayal brown to snuff brown and later almost black.

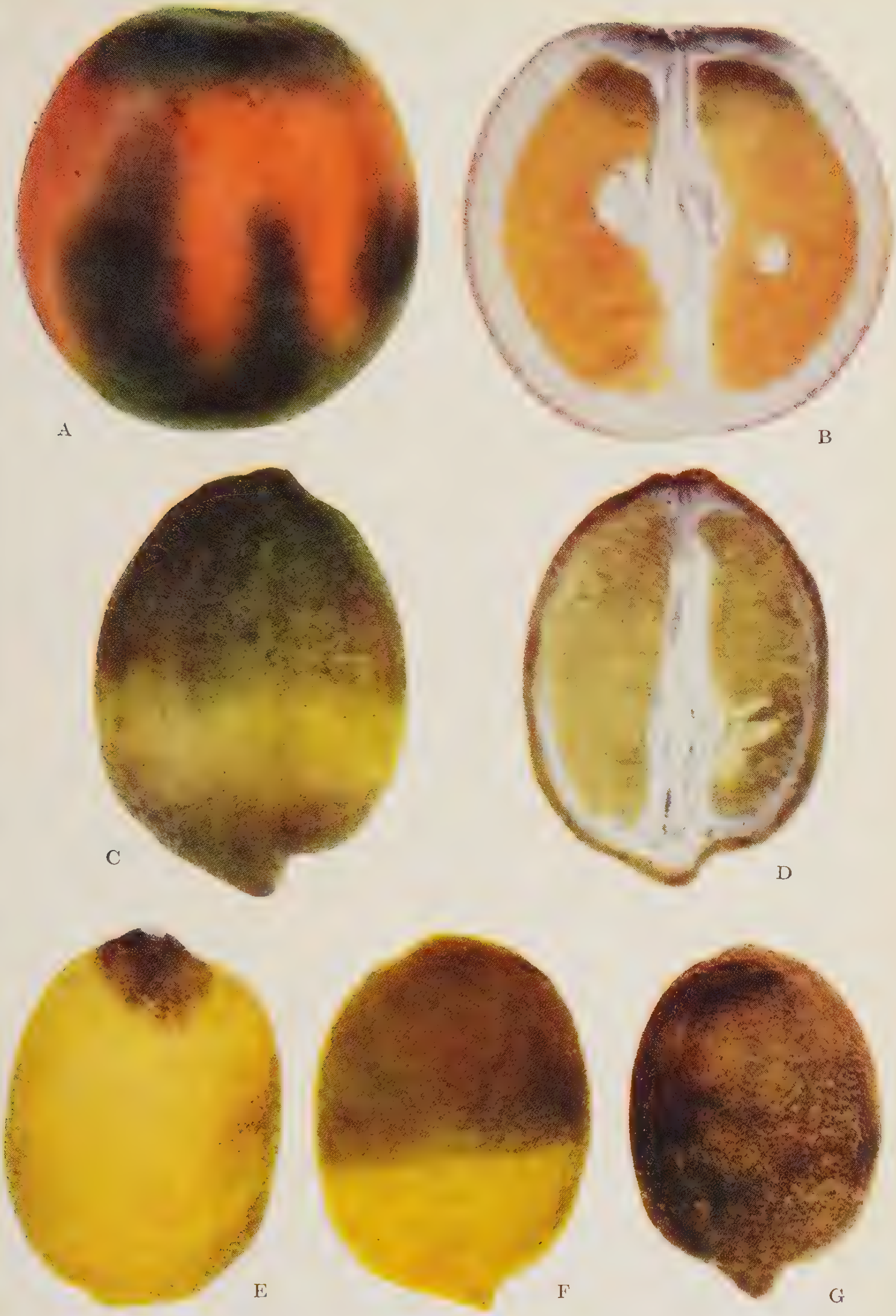

Fig. 142.—Diplodia and Dothiorella rots. A and B, Diplodia rot on orange. C and D, Diplodia rot of lemons. E, F and G, Dothiorella rot of lemon fruits. A to D produced by inoculation with *Diplodia sp.* and E to G with *Dothiorella ribes*. Both fungi from California source.

(*Facing page* 410)

bursting through, black membranous, subglobose, papillate, 150 to 180μ in diameter (Fig. 143A); spores elliptical, one septate, not constricted at septum, dark colored 24 by 15μ; exospore ornamented with striated bands (Fig. 143B). On fruits of all Citrus varieties from Natal."

The ascospore stage of the Diplodia which causes stem end rot of Citrus fruits in Florida and Cuba has been proven to be a species of Physalospora, apparently identical with *Physalospora rhodina* (B & C) Cooke. Ascospores of this fungus collected on Citrus and other hosts in these localities have been grown in pure culture and have produced pycnospores identical with what has been generally known as *Diplodia natalensis* in this country. When inoculated into Citrus fruits they produced typical end rot. (Unpublished material contributed by N. E. Stevens,[1] Bureau Plant Industry, Wash. D. C.)

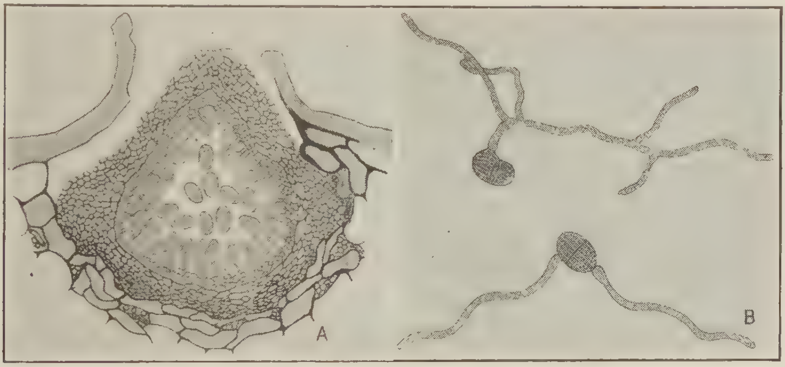

Fig. 143. —A, section through a spore-bearing body (pycnidium) of the Diplodia fungus, *D. natalensis*, pushing through the epidermis, showing the spores formed on short stalks extending from the inner wall. Magnified about 120 diameters. B, two spores germinating, magnified 165 diameters. (*After Evans* (1910).)

Contributing Conditions. The contributing factors for Diplodia rot are mainly the same as for Phomopsis stem-end rot discussed on page 408, and may be briefly summarized as follows:

1. Mature fruit or fruit that has been subjected to frost or other adverse conditions is much more susceptible than immature or sound normal fruit.

2. Unusually warm weather tends to hasten the development of the rot. The optimum temperature for rapid growth of the causal organism is about 86°F. (30°C.).

3. Moist, shady situations are favorable for the development of the fungus.

4. The presence of dead twigs and dead branches allows an increase in the development of the spores.

5. Abundance of scale insects at the stem end of the fruit may hasten the abscission rind and tend to render it more susceptible to entrance by the fungus.

Control.—The measures for prevention of Diplodia rot are mainly the same as those for Phomopsis stem-end rot, discussed on page 408.

---

[1] See also Phytopathology, **15**: 332–340, 1925.

It seems probable, however, that, since the causal fungus appears to be more resistant to copper than does Phomopsis, the spraying recommended in Florida for Phomopsis stem-end rot may not be so great a protection against Diplodia rot. The trees should be kept in a good vigorous condition and the fruit as free as possible from scale insects. As recommended by Winston, Fulton and Bowman (1923) for Phomopsis stem-end rot, under Florida conditions:

> Prune the trees and remove all deadwood, in so far as good orchard practice requires. Spray the young fruit once or twice with 3-3-50 Bordeaux mixture plus 1 per cent oil as emulsion during April or certainly before May 5, as may be required for good melanose control. Keep the fruit at low temperatures, preferably between 40 and 45°F., and shorten as much as possible the time between picking and ultimate consumption.

Removal of the buttons is another means of control first suggested by Rogers and Earle (1917) under Cuban conditions. In a series of experiments, it was shown that when the buttons on grapefruit were removed by carefully pulling instead of clipping and the stem scar shellacked, the fruit showed less Diplodia rot in storage, during shipment, than when the buttons remained. The same authors point out, however, that pulling grapefruit under Cuban conditions without tearing a portion of the rind is a difficult undertaking, but that pulling oranges, lemons and limes is more easily accomplished without injury. Under most commercial conditions there would probably be great danger in pulling fruit because of injuries in which blue and green mold would afterwards develop. Removal of buttons and treatment with bichloride of mercury and shellac have also been suggested by Earle (1920) in Porto Rico.

A method of throwing off the buttons by the use of ethylene gas has also been experimented on in Florida by Fulton and Winston (1924) and is reported to lessen, to some extent, the percentage of this rot. The use of borax in the wash water is also reported by Fulton and Bowman (1924) to be somewhat helpful though still in an experimental stage.

Experiments in connection with the Diplodia rot of the Philippines showed that dipping the fruit in fungicides not only lessened the decay in storage and transit but also hastened the coloring of the fruit, which in tropical countries normally retains its green color on the tree even after it is ripe.

DOTHIORELLA ROT

This is a leathery, pliable stem-end rot of lemons similar in its beginning stages to Phomopsis stem-end rot and to Diplodia rot. This is the first report of its natural occurrence on Citrus fruits. This fungus from other hosts was previously found to be capable of producing on inoculation a rot on grapefruit somewhat resembling Diplodia rot (Shear, Stevens and Wilcox 1924). Its effect is so nearly like that of Diplodia that the two cannot be readily separated, even in the later stages. There appears to be a tendency for Dothiorella decay on lemon fruits to turn darker more rapidly than does that of Diplodia, especially in the interior, and to be somewhat less pliable under the same conditions, but this is not an invariable difference. Oranges may also be caused to decay in a similar manner to that of lemons, as has been shown by artificial inoculations.

Symptoms.—On lemons, Dothiorella rot shows first as a slight discoloration around the "button," which soon becomes mummy brown, with an advancing band of honey yellow or honey brown (Isabelle color). The affected spot appears to be more firm at first and not so pliable as the Diplodia end rot. It may be dark amber brown to dark brown (Agnus brown, raw umber, mummy brown or clove brown). As the decay advances, it becomes leathery and pliable and may be mummy brown to dresden brown on the interior as well as the exterior (Fig. 142F, G). The decay proceeds more rapidly along the inner rind and "core" than in the pulp. When the fruit is entirely involved, it becomes olivaceous black to drabbish black (olivaceous black, fuscus or chætura black) in color. Orange fruits inoculated artificially become snuff brown or cinnamon brown on the surface and inside become cinnamon brown to cinnamon drab. As in Diplodia end rot, this decay on oranges also tends to follow the divisions producing wide bands corresponding to the division between the segments.

Causal Agent.—Dothiorella end rot has been shown recently to be due to a fungus, *Dothiorella ribis* Gros. and Dug. This same fungus has been isolated from bark lesions on lemon trees in California and has been shown by inoculations to be capable of producing a form of gummosis on lemon-tree trunks. We are indebted to C. L. Shear for identification of this fungus.

Superficially, the growth of the fungus in pure cultures has much resemblance to that of Diplodia. Its growth is quite rapid, at first, light in color, then gray and finally black or grayish black with much aerial hyphæ. On beef extract–peptone-agar, "mycelial transfers show in ten days a loose felt of short, rather fluffy mycelium on the surface of the medium" and "leave the color of the medium unchanged" (Shear, Stevens, Wilcox 1924). Fruiting or mature cultures on corn meal "show numerous raised knobs like stromatic bodies usually 2 to 3 millimeters wide and 3 to 4 millimeters high, in which pycnidia are contained." This fungus has a perfect stage known as *Botryosphæria ribis*. This species of fungus was carefully studied by Grossenbacher and Duggar (1911), who describe it as follows:

"The ascogenous form. The stromata are black and more or less pulvinate. The outer surface is botryose, resulting from extruding perithecia. The stromata are 1 to 4 millimeters in diameter, usually 2 to 3 millimeters and surrounded by the fissured periderm (Fig. 144E). They are irregularly scattered and rupture the periderm transversely, or are arranged in more or less definite, longitudinal rows which sometimes appear as single, much elongated stromata . . . The asci are clavate, measure 80 to 120 by 17 to 20μ, and interspersed among them are numerous filiform paraphyses. The spores are fusoid, continuous, hyaline, non-guttulate except sometimes in old weathered material and measure 16 to 23 by 5 to 7μ (Fig. 144A).

"The stylosporic forms. (1) The pycnidia of the compound stylosporic form are borne in the same stromata, or stromata similar to the ones bearing the perithecia, and they are usually of the same size, although frequently when interspersed with perithecia some may be more than twice that size . . . (2) The pycnidia of the simple stylosporic form are imbedded in the outer bark under the much-raised primary cortex of young shoots (Fig. 144E). They are depressed globular, 175 to 250μ wide. and usually puncture the primary cortex with papillate ostiola. The spores are fusoid, non-guttulate, hyaline, continuous, and measure 16 to 25 by 4.5 to 7.5μ" (Fig. 144B). Cultures from a number of hosts have since been studied by Shear, Stevens and Wilcox (1924), who find that a great majority of ascospores fall within the limits 16 to 23 by 5 to 7μ and pycnospores 16 to 31 by 4.5 to 8μ. It is found that the size of the stromata varies widely, depending to some extent on the thickness of the bark on which they grow. They may vary as much as 1 by 2 to 3 millimeters on smaller currant branches to 3 to 3.5 by 5 to 8 millimeters on older ones.

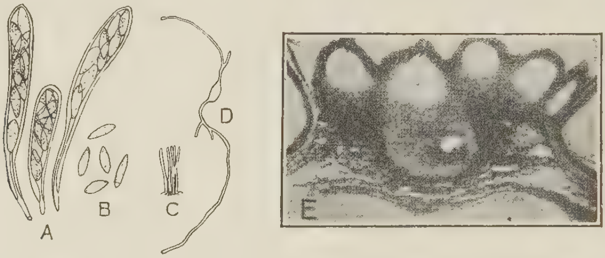

Fig. 144.—Fruiting bodies of *Botryosphaeria ribis* (*Dothiorella ribes*): A, three spore-bearing sacks (asci); each containing 8 ascospores; B, spores from pycnidia and C, the spore-bearing stalks (sporophores) of the same; D, ascospore forming initial hyphae in germinating; E, sporulating perithecia on the surface of bark tissue and an empty pycnidial cavity deeper in the stroma. A to D, magnified about 250 diameters. (*After Shear, Stevens and Wilcox* (1924).) E, magnified 10 to 15 diameters. (*After Grossenbacher and Duggar* (1911).)

Contributing Conditions and Control.—Both the contributing conditions and control for Dothiorella rot would probably be so nearly the same as that for Diplodia rot that they need not be repeated here.

CHARCOAL ROT OF LIMES

This form of decay, due to an unnamed fungus, has been observed by Wilson (1918) on limes from Florida in the northern markets and also by Nowell (1923) in the West Indies.

Symptoms.—On fresh fruit, smooth, somewhat discolored areas appear. The color varies from a deepened yellow to copper color with a margin of the spot mostly brownish. Fruits on the market show a distinctly smooth spot with elevated margin. An abnormal odor and color are found upon opening the fruit. After fruits have dried and mummified, they are found to be filled with black, hard masses of fungus mycelium.

The Causal Fungus.—Wilson (1918) has grown it in pure culture and reproduced the rot in limes by inoculation. No fructifications were found in connection with the causal fungus, and it has, therefore, not been identified. The growth of the fungus (Fig. 145) is at first white and cottony. In prune juice, it forms radiating knots of mycelium on the surface, which later form a coal-black mass. This was found to consist of dense brown mycelium readily breaking up into minute segments, making a dry black powder from which fruits could be infected. O. F. Burger writes us that he had obtained Diplodia from this type of decay in Florida where the decay is quite common on limes. We also obtained Diplodia from a decay of limes on the eastern markets similar to this one and believe that Wilson's fungus may have been the sterile mycelium of Diplodia which does not alway produce spores readily in the usual culture media and is black and carbonaceous with age.

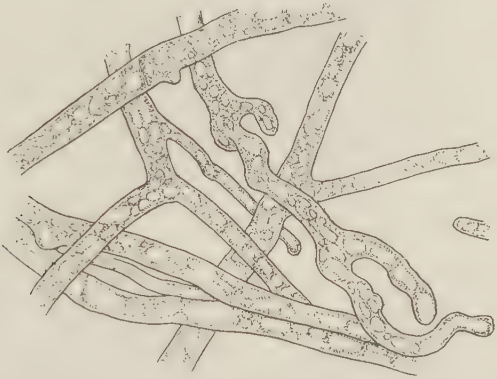

Fig. 145.—Hyphal threads of charcoal fungus of lime greatly magnified. (*After Wilson* (1918).)

INSPISSOSIS OR DRY ROT OF FRUIT

Inspissosis, or dry rot, due to a fungus of the genus Nematospora, consists in a drying of the vesicles and internal tissues of the fruits. usually without any external symptom whatsoever. The name dry rot is not entirely appropriate, since the disease is not a rot in the usual sense and does not result in any discoloration of the flesh. In advanced stages, the juice vesicles, in addition to being dry, are greatly inspissated or thickened, from which condition the term "inspissosis" is suggested. Knowledge of this disease has developed only within recent years, and there is very little literature on the subject.

Distribution and Host Plants Affected.—Inspissosis was first brought to the attention of investigators from the Philippines, where it appears to be of very general occurrence (Lee 1924). It is also commonly found in Citrus fruits in south China, in almost all regions where Citrus fruits are grown. Affected fruits have also been observed in Japan. It was not observed in Java, and there are no reports of it from other countries of the eastern hemisphere, although there is a report of a similar disease, probably identical, in the West Indies (Nowell 1923). The disease is not known in Florida or California and has not been reported from countries of the western hemisphere other than the West Indies.

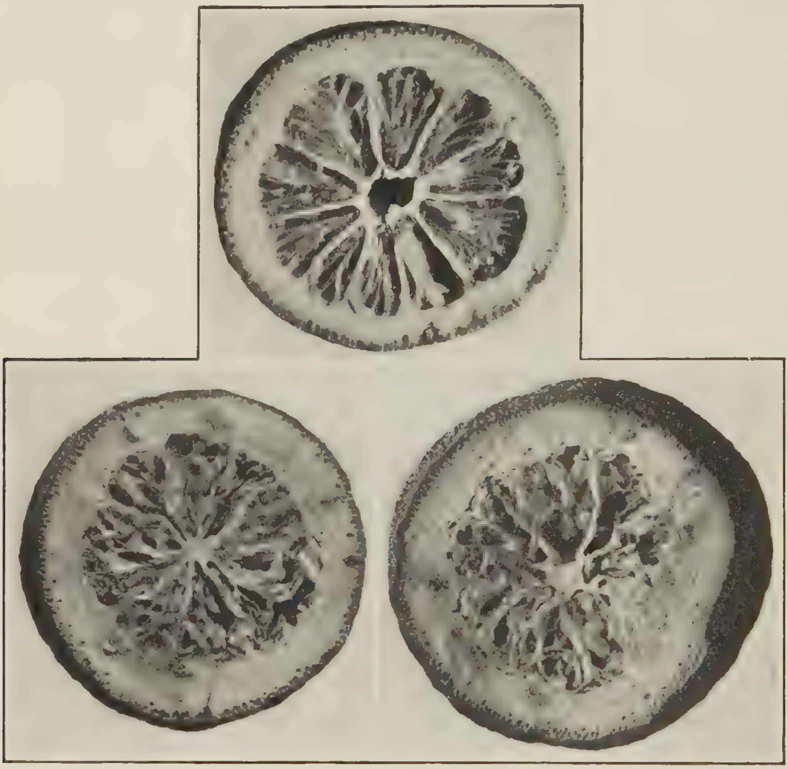

Fig. 146.—Above, a normal sour orange, *Citrus aurantium*, for comparison with the fruits of the same species below, affected with dry rot, due to Nematospora.

The disease affects only the fruits. It has been found in fruits of the sweet orange, *Citrus sinensis*, the mandarin orange, *C. nobilis* var. *deliciosa*, the calamondin, *C. mitis*, and the sour orange, *C. aurantium*. There are doubtful cases on record on fruits of the satsuma, *C. nobilis*, var. unshiu. It has not been observed upon fruits of the grapefruit or pummelo, *C. maxima*, the lemon, *C. limonia*, the lime, *C. aurantifolia*, or the cabuyao, *C. hystrix*. Species of Nematospora have also been noted in Italy in hazelnuts by Peglion (1901), in tomatoes from Cuba or Mexico by Schneider (1917) and in fruits of at least fifteen other hosts in the West Indies by Nowell (1923).

Symptoms.—There are no external symptoms. On cutting into a fruit from the Philippines or from China or Japan, an abnormal condition is often evidenced by the thickness of the section walls, as shown in Fig. 146. The section walls appear to be of a mealy texture, white, and as if dividing into separate membranes. Sometimes, however, the early stages of the disease will be evidenced by a dry and brittle condition of the flesh. The individual vesicles, in such cases, separate easily from each other and, according to the advance of the disease, are more or less dry and free of juice. As the drying advances, the vesicles become wrinkled, atrophied and entirely separated from each other, as shown in Fig. 147. Sections of such a brittle, dried vesicle shows the walls to have become considerably thicker than the walls of a normal vesicle. In advanced stages of the disease, the vesicles have an even greater degree of inspissation and are entirely devoid of juice.

The fruits in the early stages have an unpleasant sourish taste, but in advanced cases become dry and almost entirely tasteless. The brittle manner with which the flesh crunches when chewed, suggests very much the brittleness of a cabbage. The disease sometimes is found to be confined entirely to one or two sections of the fruit, the remaining sections being entirely normal, as shown in some of the fruits illustrated in Fig. 147. Just as frequently, however, the whole fruit exhibits this drying-up condition. In very bad cases, the normal semblance of the flesh is entirely lost and the section or the whole fruit becomes a mass of nearly dry, stringy vesicles, sometimes of a deeper-orange color than the normal flesh. There is never any blackening, unless secondary rots follow, and this occurs in but a small proportion of cases. A disease of similar character has been reported on tomatoes in tropical countries, on hazelnuts in Italy and in cotton bolls in the West Indies.

Economic Seriousness of the Disease.—The initial loss caused by this disease is to the consumer who buys the fruit as a good orange, judged by its external appearance, but upon eating finds it dry, tasteless and devoid of juice. The loss will sooner or later, however, ultimately be felt by the retailer, the wholesaler and finally the grower. In the Philippines, the growers, having produced a crop of fruits more or less affected by the disease one year, find it hard to dispose of their crop the following year. The effect would probably be the same in other countries, should the disease become established there. Such a condition occurring in Florida and not in California would greatly injure the Florida industry, and *vice versa.*

The disease in the Philippines may be very serious one year and may be scarcely noticeable for several successive years. Apparently, seasonal conditions, such as constant rainfall or some other unfavorable factor has an important influence on its occurrence. Peglion (1901) has mentioned the same variation in the occurrence of the Nematospora disease of hazelnuts.

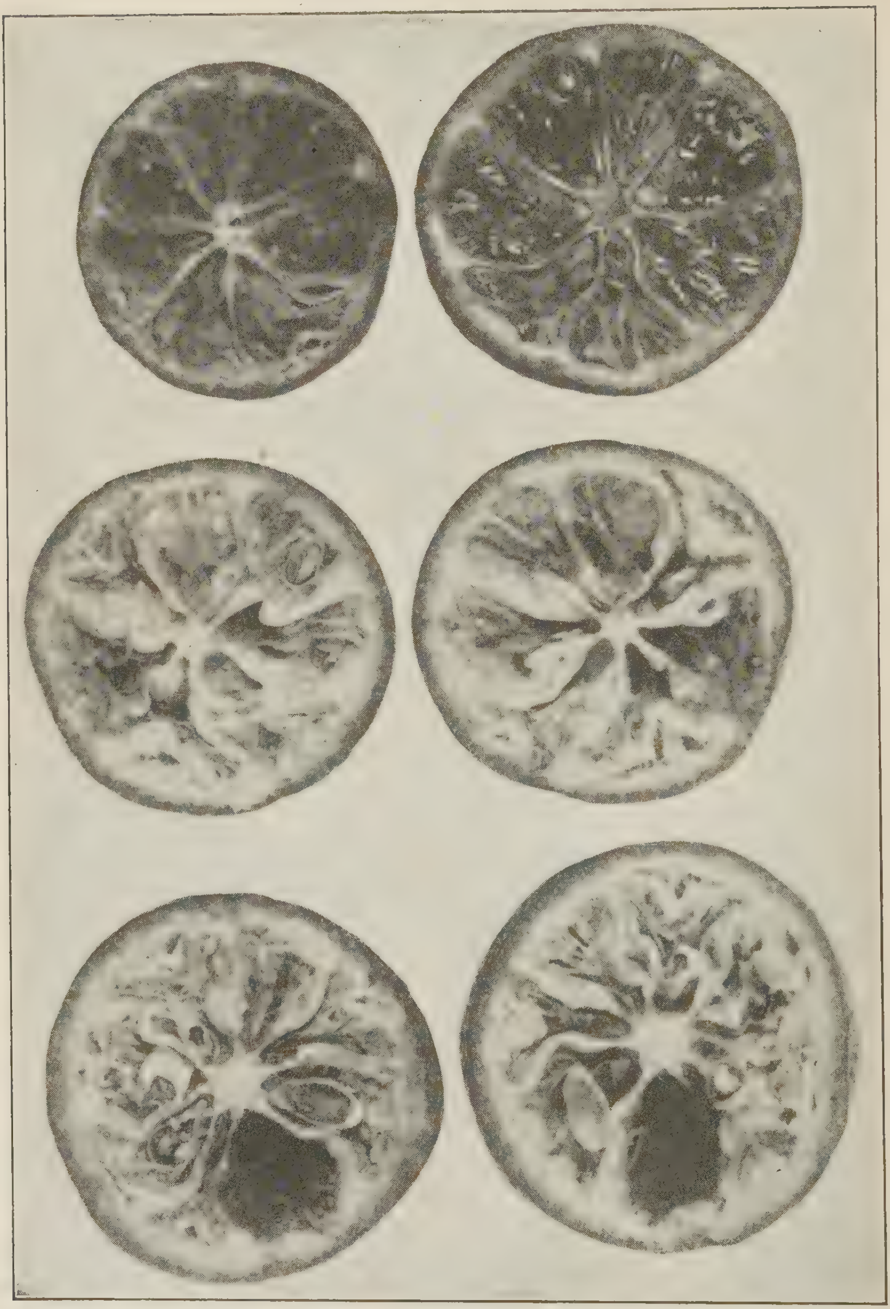

FIG. 147.—Calamondin fruits, *Citrus mitis*, affected with dry rot; above showing the thickened section walls and below showing advancing stages of the disease, due to Nematospora.

The Causal Agent.—Yeast cells and peculiar long, slender, needle-like spores were observed by Lee (1924) to be constantly associated with the disease, and subsequent inoculations showed that the condition could be reproduced in a large proportion of trials by introducing this fungus into healthy fruits. The following is extracted from the description by Lee of the fungus, which is a species of Nematospora:

> In culture and on slides from affected fruit tissue, no considerable mycelium has ever been observed, although occasional small bits of irregular-appearing hyphæ may sometimes be found. The only forms of the organism observed from fruits and from cultures are ordinary yeast cells, much larger, rounded cells, club-shaped bodies and sporangia and spores (Fig. 148). All the forms frequently may be seen on one slide from affected orange tissue. The yeast cells are ellipsoidal, approaching spherical, but not distinctive. The nature or function of the large round cells and the club-shaped bodies is difficult to comprehend; the walls of these bodies are slightly thicker than the walls of the yeast cells or of the sporangia, but, other than this and their peculiar shape, nothing can be said of their nature. The sporangia and spores are very distinctive; what appear to be young, newly forming sporangia are developed by the enlargement of a single cell and are thin walled, hyaline and elongate. Each sporangium observed contains two groups of four closely compacted spores; that is, eight spores to each sporangium.
>
> The spores are extremely long and slender, narrowing gradually at one end into an extremely long appendage which has the appearance of a flagellum. The contents of the spores are rather densely granular and with a peculiar lessening of granulation in the upper half of the spore farthest from the appendage, as shown in Fig. 148. Slightly above the middle of the spore, regarding the appendage as at the lower end, is a distinctive area of almost entire absence of granulation, which in some spores has the appearance of being a cell wall. It is not seen in the young, less mature spores, and careful observation of many spores leads to the opinion that this is not a definite cell wall. A slight projection appears on each spore just below this area devoid of granulation, and this projection, the flagellum-like appendage and the markedly

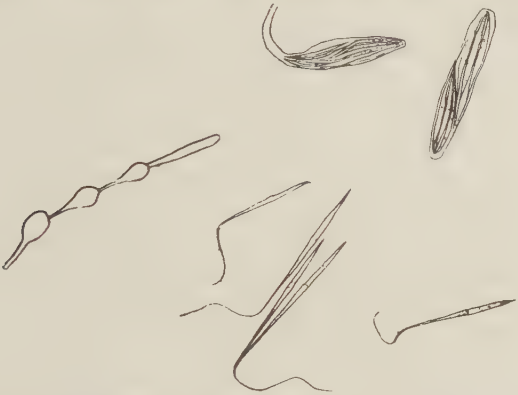

FIG. 148.—Above, to the right are shown the asci of the causal fungus of dry rot, each ascus enclosing 8 ascospores in 2 clusters of 4 spores each. Below are the long, slender ascospores showing the thinning granulation towards the tips, the projection of the cell wall just below this thinning granulation, and the long appendages. To the left is one of the anomalous club-shaped bodies.

lessened granulation in the upper end of the spores are the distinctive characters of the spores. All of these features are shown very definitely in Fig. 148. These characters are seen readily in the spores without staining, but with carbol fuchsin or gentian violet are shown more clearly.

The spores are also shown in Fig. 148, lying in the sporangium in characteristic position. The spores lie with their thinly granulated ends toward the extremities of the sporangia, while the appendages from one group of four spores overlap the spores of the other group. The sporangia are usually 75 to 110 by 6.5 to 20μ in size, and the spores vary from 42 to 66μ in length and are usually 1.5 to 3μ at their greatest width. The appendages are from 11 to 40μ in length. It is rather difficult to determine which point should be taken as the end of the spore and the beginning of the appendage.

The yeast cultures readily and makes a quick growth on nutrient beef agar and a very copious growth on potato cylinders. On agar plates, the growth resembles that of bacterial colonies more than that of a fungus; growth is rapid at laboratory temperatures of 28 to 30°C., round to irregular, rather grayish or dirty white, raised to pulvinate, surface irregular and hummocked, edge entire and internal structure granular. The colony is of an easily separated consistency, and there is no marked or characteristic odor.

Contributing Conditions.—Nowell (1917*b*) has shown in the case of internal disease of cotton bolls, which is caused by a similar fungus of the genus Nematospora, that transmission of the disease is by means of insects. By analogy, it seems probable that this disease of Citrus fruits is similarly transmitted by insects. A fact also pointing to this indication is that the thick-skinned Citrus fruits are for the most part not affected, while the thin-skinned fruits, such as the mandarin oranges and calamondins, are much the most commonly affected.

In the inoculation work by Lee (1924), it was found that young green fruits are not susceptible, but that, as the fruits approach maturity, the disease can be induced much more readily by inoculation with the fungus.

Although the disease is much more common in the Philippines than in other Citrus countries of the Orient, it was found in mandarin orange fruits as far north as Foochow in China, indicating that the disease is not confined to the tropics but can develop in the Citrus-growing regions in the lower latitudes of the temperate zones.

Prevention.—For those countries where inspissosis does not yet occur, such as Florida and California, entire exclusion of the disease is, of course, the cheapest remedy. There is some evidence, obtained from spraying experiments against other diseases, that fungicides can be used effectively to prevent it. Spraying with fungicides, further studies to determine the insects which serve as carriers for the disease and efforts to control such insects should be carried out in countries where the disease is of common occurrence.

CHAPTER XVII

INTERNAL NON-PARASITIC MALADIES AND GENERAL EFFECTS

ENDOXEROSIS OR INTERNAL DECLINE OF THE LEMON

Endoxerosis, or internal decline, is a term applied to an abnormal physiological condition of lemon fruits, usually at the stylar end. A number of local names have been used by growers and shippers such as "tip deterioration," "yellow tip," "dry tip," "blossom-end decay," etc. This disease, when not accompanied by the entrance of organism, is an internal breakdown involving drying, gummy degeneration and discoloration without softening or rotting in the usual sense. It is an orchard disease, first appearing in May or June and having, under California conditions, its maximum development in the dry summer and autumn season, at which time it brings a serious problem to the packing house and to the markets. Internal decline is frequently confused with Alternaria rot, which often accompanies or follows it (p. 389). Before the disease was carefully studied, the combined effects of internal decline and Alternaria rot was frequently referred to as "physiological decline."

History and Distribution.—This trouble appears to have been known to lemon growers in California for at least twenty-five to thirty years, but has not been studied or described until recently. This malady along with membranosis became especially troublesome in the years following the freeze of 1913 in California when much attention was called to them by growers and shippers. When the study was first taken up, both of these physiological maladies were included under the term "internal decline." Internal decline, however, is now considered primarily a summer or dry-season disease developing in the orchard, while membranosis is a winter or wet-season disease developing in storage. One is probably the antithesis of the other as to causal factors. The study of internal decline was first begun by Barrett and Fawcett in 1914 (Bartholomew, Barrett and Fawcett 1923), and was later taken up intensively by Bartholomew (1923*b*, 1925), whose work has contributed to an understanding of the nature of the malady and some of the causal factors involved in its occurrence.

A disease of lemon fruits was reported in Queensland, Australia, by Jarvis (1914), which from his description would suggest a similarity in some features to internal decline. In the final stages, the fruit is described as having a faint-yellow tinge, abnormal dryness and a tendency to be undersized, to ripen prematurely and to drop from the tree.

Pale brownish-yellow blotches and darker brown markings extending into the fruit pulp are mentioned. Later, the central core is said to become dark brown and to be filled with gum and portions of the peel next to the fruit pulp to show dark-brown gummy degeneration.

Symptoms.—The most striking characteristic of well-developed cases of endoxerosis or internal decline in California is a breaking down or drying of the internal tissue back of the stylar end, accompanied by a pinkish to brownish discoloration. The extent of the breaking down of the tissue varies but may involve the pulp and parts of the inner portion of the peel of one-fifth to one-half of the interior of the lemon fruits. Gum formation or gummy degeneration in or next to the peel is a common symptom. When one-half or more is involved, the fruits usually drop. The symptoms vary with the age of the fruit.

On Green Fruit.—Externally, a loss of luster or the development of an orange-yellow color near the stylar end while the rest of the surface is quite green is a sign, though by no means invariable, of the presence of the trouble (Fig. 149E). Internally, the white portion of the peel at the stylar end may show a gummy mass, pinkish or rust brown in color accompanied by a partial drying and collapse of the tissue. Blotches similar in nature may appear in any part of the white portion of the peel. One of the first symptoms is the appearance of very small cylindrical openings arranged in a circle within the ring of vascular bundles in the "nipple" of the peel at the stylar end. These are produced by the collapse of the parenchymatous cells. Another common symptom is an oozing of a small amount of clear gum from the vessels. This gum appears to be under pressure, which results in its oozing out on cutting. Later the vessels and the surrounding tissues become clogged with a deposit of gum, which is followed by the tissue becoming pinkish to rust brown in color. In the "buttons," and also the twigs bearing affected fruits, the clogging of vessels with gum has been found by Bartholomew to extend 1 to 4 centimeters or more back of the button. The twig, therefore, as well as the fruit, becomes involved (Figs. 150, 151).

In "Silver" and "Tree-ripe" Fruit.—Externally, it becomes more difficult to detect the presence of internal decline at these stages. A more intensive coloring of the peel at the stylar end is sometimes, but not always, a sign. Depressions may also appear on one side of the stylar end with a bending over of the "nipple." The lighter weight of the stylar end in advanced stages may also cause such fruit to float in the washing tank with this end upward. Internally, there will be found an extension of the conditions described in green fruit until parts of the inner peel and more of the pithy core are involved, with loss of water and a collapse of pulp cells and juice sacks at the stylar end (Fig. 149C, D). As the fruits become tree ripe, the pulp cells continue to lose water and collapse. In some cases, the malady may not begin until the "silver"

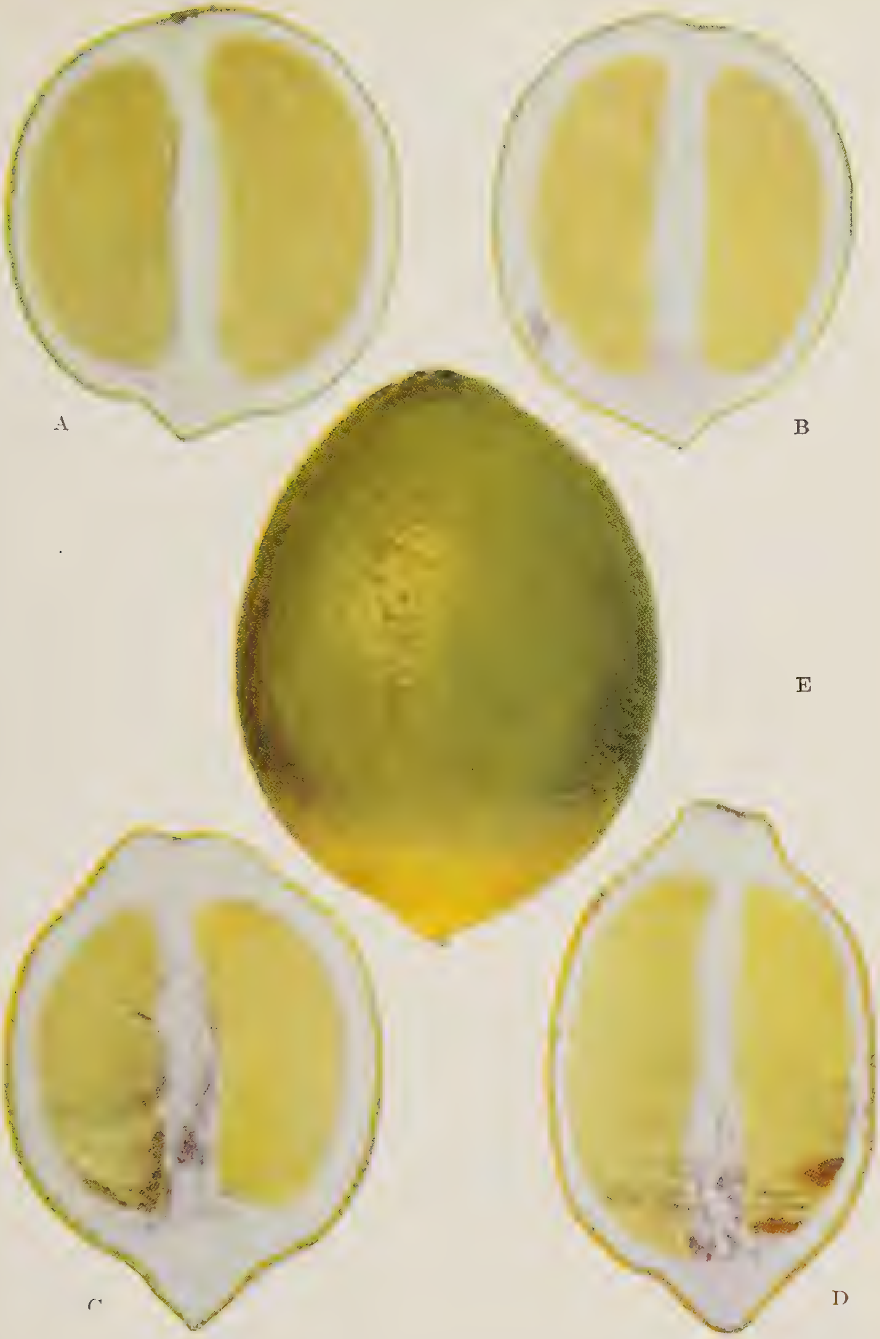

Fig. 149.—Endoxerosis or internal decline of lemon fruits. A to D, Showing different stages in the development of internal symptoms of breakdown and discoloration. E, Showing the external symptom of yellowing prematurely at stylar end around the "nipple"; fruit in about the stage represented by B. (*Photo contributed by E. T. Bartholomew.*)

(*Facing page* 422)

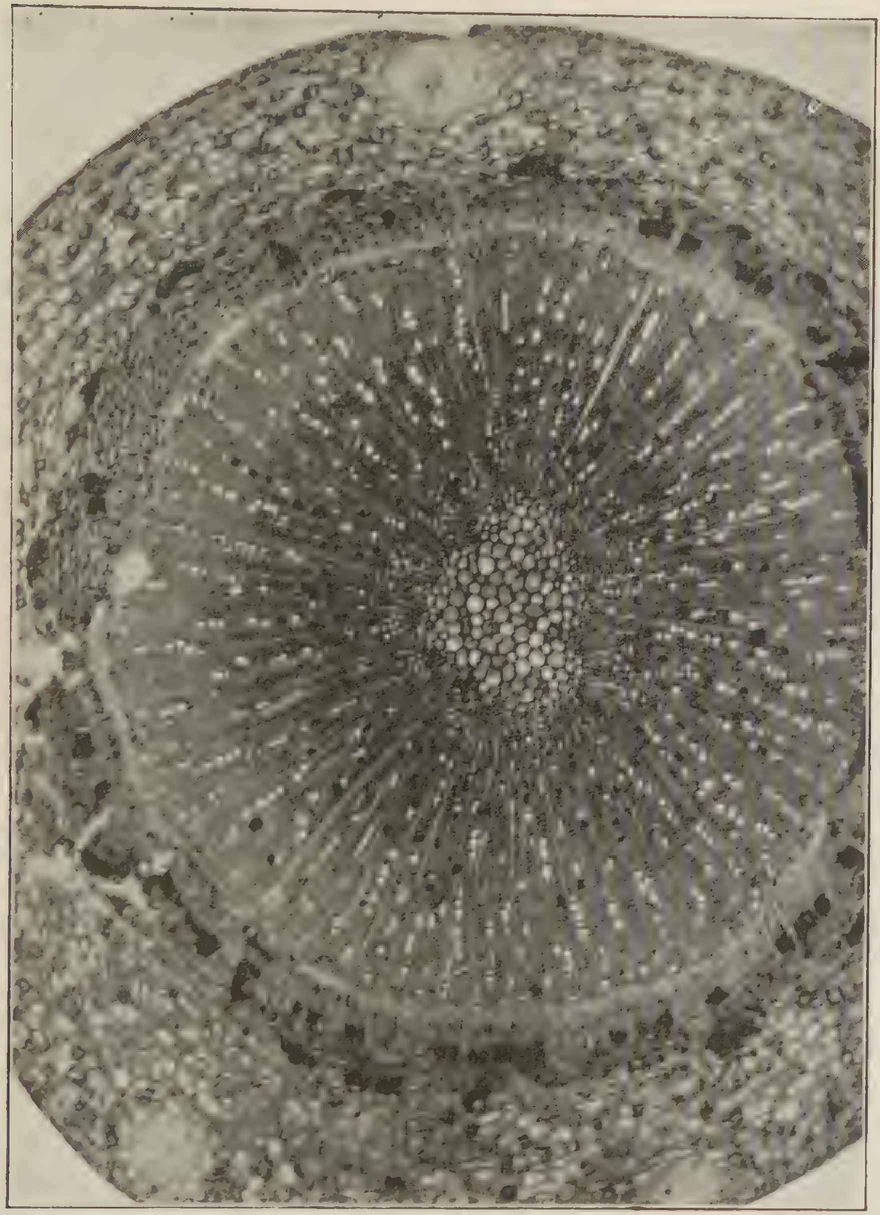

Fig. 150.—Cross section of a stem immediately back of a fruit that was affected with endoxerosis showing plugs of gum in some of the wood vessels which surround the central pith cells. From center to circumference is seen: rounded pith cells; ends of wood vessels with medullary rays dividing them in segments; cambium region; inner bark containing the sieve tubes into which an extension of the medullary rays is seen; an interrupted circle of darker patches the ends of bast fibers; the outer bark containing the cortical cells, an occasional oil vesicle light in color, and an outer thin cuticular layer. Compare with Figs. 72, 93, 151. Magnified about 18 diameters. (*Photo contributed by E. T. Bartholomew.*)

and "tree-ripe" stage, in which case the gum formation may be less abundant.

Causal Conditions.—So far as now known, endoxerosis, or internal decline, is a physiological abnormality, in no way associated with microorganisms of any kind. The principal causal factors, as shown by Bartholomew (1923*b*), appear to be related to water conditions within the tree and fruit, and these are, in turn, influenced by moisture conditions in air and soil and physiological conditions of the tree itself. Seasonal conditions, with large daily fluctuations of temperature accompanied by low humidity during a greater part of the day, are especially favorable for development of internal decline. Under such conditions, even with optimum soil water, the lemon tree appears to have difficulty in supplying sufficient water to make up for the very rapid transpiration from its leaf surfaces. It is well known that as the Citrus leaves begin to suffer they tend to draw water away from the fruit (Coit and Hodgson 1919, Bartholomew 1923*b*, 1925),[1] and there is a strain on the water relations which, if made up at all, must be made up during the night. During long periods of dry, hot weather of this kind, the fruit may actually suffer marked deficien-

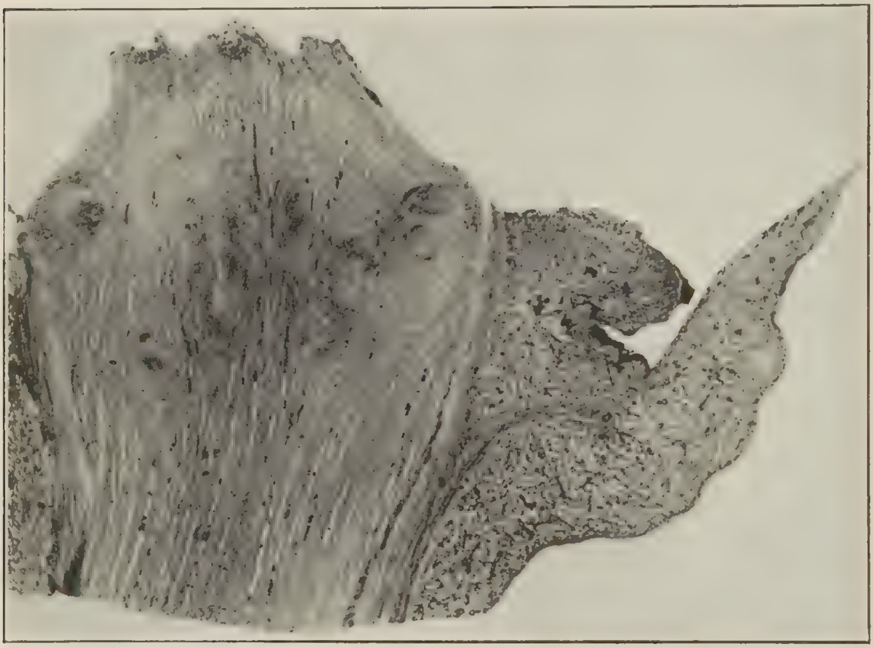

Fig. 151.—Longitudinal section of a "button" or end of stem from which a lemon fruit affected with endoxerosis has been pulled off, showing plugs of gum as dark lines in the wood vessels. A section through the calyx cup is indicated in the right of the woody part. Compare with cross section of Fig. 150. Magnified about 10 diameters. (*Photo contributed by E. T. Bartholomew.*)

---

[1] See also Bartholomew in Am. Jour. Bot., Feb. 1926.

cies, even under the best conditions of irrigation. If water in the soil is also insufficient, the strain is, of course, much greater. It has been observed that in localities near the coast during summer seasons when the air is relatively humid, internal decline is much less prevalent than in the drier interior valleys. Although the experiments so far indicate that the water relation is the most important factor, yet they also indicate that other factors associated with the water relation have important influences in the occurrence of the malady.

Control. *In the Orchard.*—Since the causal conditions appear to be closely related to water conditions in the tree and fruit, the methods of prevention consist in keeping these as favorable as possible. Certain adverse climatic conditions can be partially alleviated. The effect of drying winds during periods of low humidity may be partially overcome by suitable windbreaks. Systems of overhead sprinkling or devices for keeping the air more humid during periods of stress might be suggested as a possible means of prevention. Keeping the soil at optimum moisture conditions with good root development is also important in times of low air humidity. Keeping the soil well supplied with bulky organic materials that improve the water-holding capacity of the soil is another means of avoiding some of the water deficiency. Keeping the trees protected from injurious shocks, such as frost injury, sunburning or extremes of any kind, will also probably aid in the prevention of excessive internal decline. For future plantings in districts or climates especially subject to internal decline, it may be advisable to look toward finding a rootstock or variety of lemon or both better suited to resist the strain in the water relations to which they must be subjected. This is a matter for further investigation.

After the internal decline begins to appear, its effect on the grade of fruit may be partially overcome by keeping the fruits picked regularly before they become too old or "tree ripe." Many California growers under such conditions pick the fruit unusually close, even though this necessitates taking off a considerable number of small-sized and even undersized fruits. It may be necessary, in bad summer and fall seasons, to pick with an extra small ring and take everything that is up to that size and to pick all fruit that shows much color irrespective of size.

In the Packing House.—In the packing house, internal decline presents a serious problem because of the difficulty, at times, of eliminating affected fruits from the best grades. Although internal decline as such does not appreciably increase or develop further after the fruit is picked, it does seriously impair the quality of the fruit and seriously lower its resistance to fungus rots and especially to Alternaria rot (see p. 389). A large percentage of internal decline can usually be eliminated by expert graders merely from external appearances. A slight off color at the stylar end or "nipple," a bending of the nipple and a one-sided development cause the fruit to be thrown into a lower grade. In well-developed cases in tree-ripe fruit, the position in floating, because of the light stylar end, makes it easy to pick out the fruit at the washer or at a special "floating tank."

A study of methods of eliminating internal decline under packing-house conditions was made by Williams (1921), who suggests that the best method is to segregate the fruit as far as possible at the washer and as it comes out over the belt before it is set aside for curing. By exercising great care in culling and checking up on the graders' judgment or skill and by frequent cutting of small lots of fruit, it has been found possible, in most houses, to cull out a major portion of the internal decline. In doing so, about 10 per cent of sound fruit will be found among that culled out. In some cases, it may not be possible to cull without leaving as much as 25 per cent of sound fruit among those eliminated. This sacrifice, however, is usually worth while in order to protect the reputation of the better brands of fruit on the market.

HOLLOW CORE

A condition of lemon fruits which can scarcely be called a disease, but which sometimes precedes or accompanies internal decline, is that known as "hollow core." Fruits cut longitudinally (Fig. 152) will show a cavity where the spongy tissues of the central axis or core have pulled apart. This "hollow core" may or may not be accompanied by a certain amount of drying out in the surrounding segments. There is usually a looseness of the peel accompanying the hollow core. The drying usually starts back of the tip, but in tissues situated inward, for a distance greater than the thickness of the rind. This hollow condition at the core, at first, may extend only one-fourth to one-third the length of the fruit, but sometimes extends nearly the whole length with the exception of the part occupied by the rind.

In "hollow core" not accompanied by internal decline or other maladies, there will be no discoloration or gum formation. The hollow core may be sometimes related to, but not necessarily a stage of, internal decline. It should be pointed out that some varieties of Citrus fruits may normally possess a hollow or empty place in the core when mature.

JUICE-SACK GRANULATION

A dry and granulated condition in the interior of the fruit, especially when it has been left on the tree a long time after maturity, sometimes gives a great deal of trouble, especially on fruit picked late in the season. It is often referred to by growers as "crystallization," though it is not apparently due to any formation of crystals.

The impression of crystalline structure has been found by E. T. Bartholomew to be due to a separation of individual cells, usually near the center of the juice sacks, allowing air to enter, thus giving the sacks a clear white appearance in comparison to the bright normal color of the juice sacks. The walls of the sacks become stiffened, and the sacks become hard and firm instead of flabby. Cutting through these juice sacks with a knife reveals a solid or a dry woody condition.

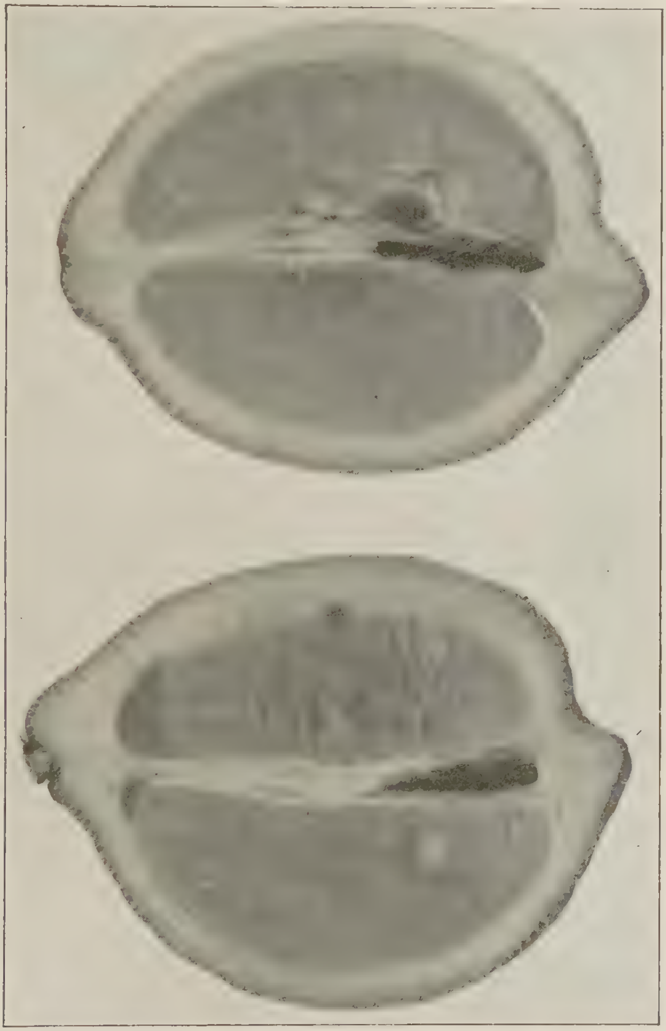

FIG. 152.—Section of lemon fruit showing "hollow core." This may frequently occur without discoloration of any of the surrounding tissues. It may be related to but not necessarily a stage of endoxerosis or internal decline. There is no discoloration in the hollow part as might be supposed from the black color in the illustration in the portion represented by the cavity.

This juice-sack granulation usually begins near the stem end and extends first down near the core. It is found especially on mature Valencia oranges late in the summer or fall. It takes place while the fruit is on the tree and apparently increases very little after picking. Slight frost injury appears to be a contributing condition, although it sometimes appears to develop where fruits have not been known to have been subjected to any frost.

Losses from this juice-sack granulation may be lessened by picking the fruit before, or as soon as, the condition begins to appear.

MEMBRANOSIS OR MEMBRANOUS STAIN

Membranosis is an internal breakdown or stain of lemon fruits also known in California as "membranous stain." In the early study of internal decline, it was considered a phase of that disease. Membranosis in California differs from internal decline as now considered in that it is a trouble developing after picking, while internal decline is a malady developing while the fruit is still on the tree. Also, membranosis usually is a cold, wet-weather trouble, while internal decline is usually a hot, dry-weather disease. Membranosis was also found in a severe form in Cincinnati, Ohio, in the summer of 1924 in Italian fruits that had been in cold storage for over three months.

Symptoms.—The membranes or carpellary walls between the segments show irregular stained areas, brown to black (Fig. 158C). The central core tissue may also become stained, and sometimes, although less frequently, stain will be found in the tissues of the inner rind. There are no external symptoms, although peteca and red block on the surface frequently accompany the disease. The irregular stained patches, varying in size from mere dots or streaks to large areas involving an entire membrane, are dark yellowish brown to sepia (brussels brown, raw umber or sepia per Ridgway 1912). Membranosis is most easily detected by cutting the fruit lengthwise from button to nipple. The stain is seen on the divisions or membranes and not in the pulp cells or juice sacks. Fruit cut transversely, as is generally done in extracting the juice, shows only the edge of the stained membranes as a narrow brown line. The juice is not perceptibly affected till membranosis spots have occupied a large percentage of the membranes. In less severe cases, it will not ordinarily attract serious attention on transversely cut fruit.

Contributing Conditions.—Membranosis develops in storage or transportation under much the same weather or seasonal conditions as does peteca and red blotch. It often accompanies these two manifestations, but any one of the three may occur alone. Membranosis seldom develops except in fruit picked in the cool, damp season of late autumn, winter or early spring in California. It appears to be prevalent in unusually damp and cold winter seasons. It appears as a rule to be worse in seasons following a hard "freeze" on fruit that has developed after the trees were weakened, but not necessarily on fruit that was on the trees at the time of the freeze. In addition to these factors, there are orchards whose fruit appears to be inherently more susceptible to membranosis than others in the same district when subjected to exactly the same storage conditions. Lack of ventilation may also be a contributing factor. This disease, together with peteca and red blotch, requires further investigation as to nature and control.

Control.—The information given above serves only to suggest the most general and indirect methods of prevention. As in peteca, the growing of strong trees, as far as possible protected from severe shocks, extremes of temperature, wind, water, etc., may assist in producing resistant fruit. When membranosis is slight in extent, it may not seriously affect the quality or taste of the fruit; when severe, however, it weakens and impairs the internal appearance and even the taste of the juice, so that the grade is seriously injured. Fruits badly affected should be culled or put into very low grades; those with very slight affections may not attract the attention of either the packers or buyers.

FROST INJURY

Fruits affected by frost show certain external and internal effects, which may, in some cases, be mistaken for diseased lesions. These effects are also closely connected in some cases with decay-producing organisms. The fruit affected by frost, even when the tissue is not badly killed or destroyed, is rendered susceptible to the invasion of many types of fungi which would not readily enter sound uninjured fruit.

External Effects of Frost Injury on Fruit.—One of the most conspicuous external effects of frost is the appearance of spots like those produced by oil liberated from the rind (Fig. 153B). In fact, it has been found that during the process of freezing, the smell of oil can be detected. These spots are therefore due, as in other cases, to the oil which is discharged from certain of the oil glands and which oozes out on the surface. Such spots are characterized by the tissue between the oil-bearing cells becoming sunken and later turning brown as the fruit remains on the tree, while the tissue above the oil glands themselves remains undisturbed. In some cases, the degree of spotting is an indication of the degree of freezing, but this is by no means an invariable rule. Some types of fruit do not readily show the oil spots, even when severely injured internally. Moreover, not all fruits on the same tree will show the same degree of injury from spotting. It was noted after the freeze of 1913 that fruit spotting usually showed more often on the north than on the south side of the tree. Lemons and grapefruit were apt to show them more readily than oranges, and tangerines less than the oranges. When freezing is more severe, watery patches of considerable size may appear, especially on lemon fruits (Fig. 153A). These patches, if the weather is moist, are invaded by a black mold and soon begin to rot on the tree. Under such conditions, the fruit may be attacked by Botrytis, Penicillium, Cladosporium and other fungi.

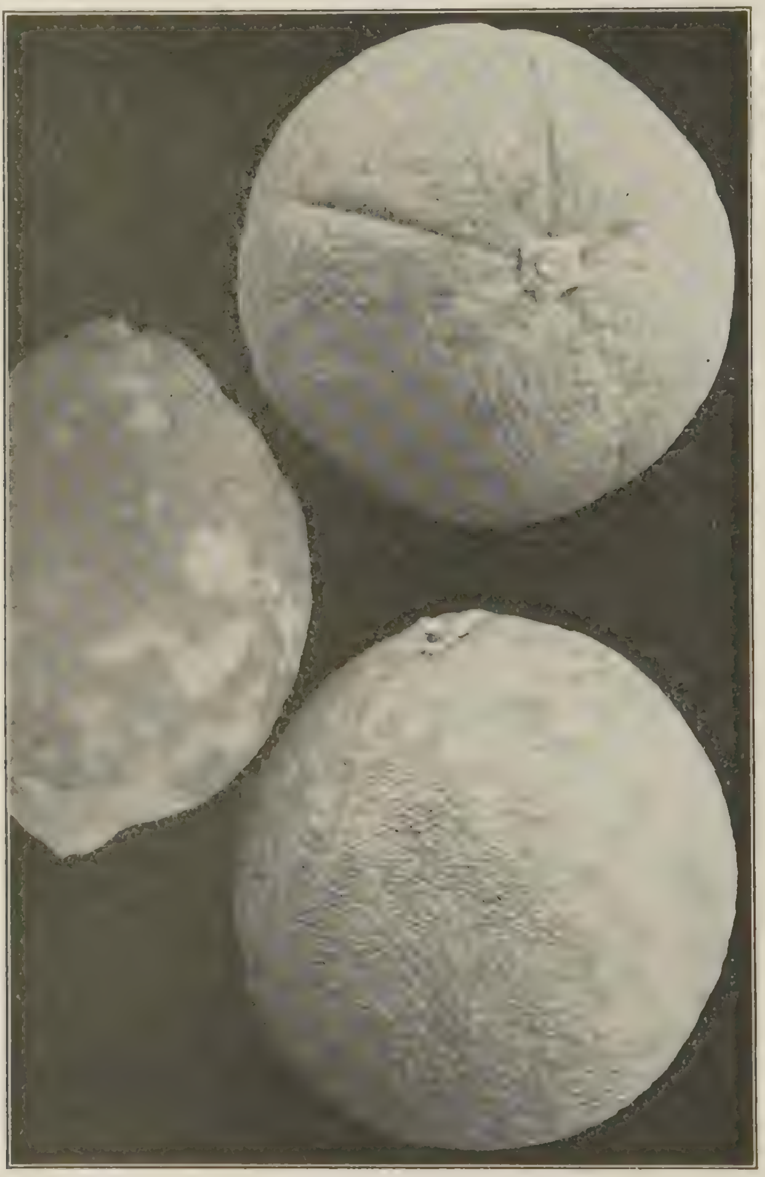

FIG. 153.—Spots on surface of orange and lemon fruit as the result of freezing. A, white spots on severely frozen lemon; B, oleocellosis spots on oranges due to oil liberation from the oil glands. (*Photo by C. O. Smith.*)

Internal Effects.—The earliest frost effects to be noted internally are either water-soaked areas on the membranes, or the formation of white spots, composed of crystals of hesperidin, on the membrane or pulp (Fig. 154). These are usually seen within five or ten days after freezing and appear on the membranes in oranges and lemons, but scattered through the pulp in tangerines. They are best seen by cutting the fruit transversely and pulling the segments apart. The pulp cells are also apt to tear apart more easily in frozen fruit than in sound fruit.

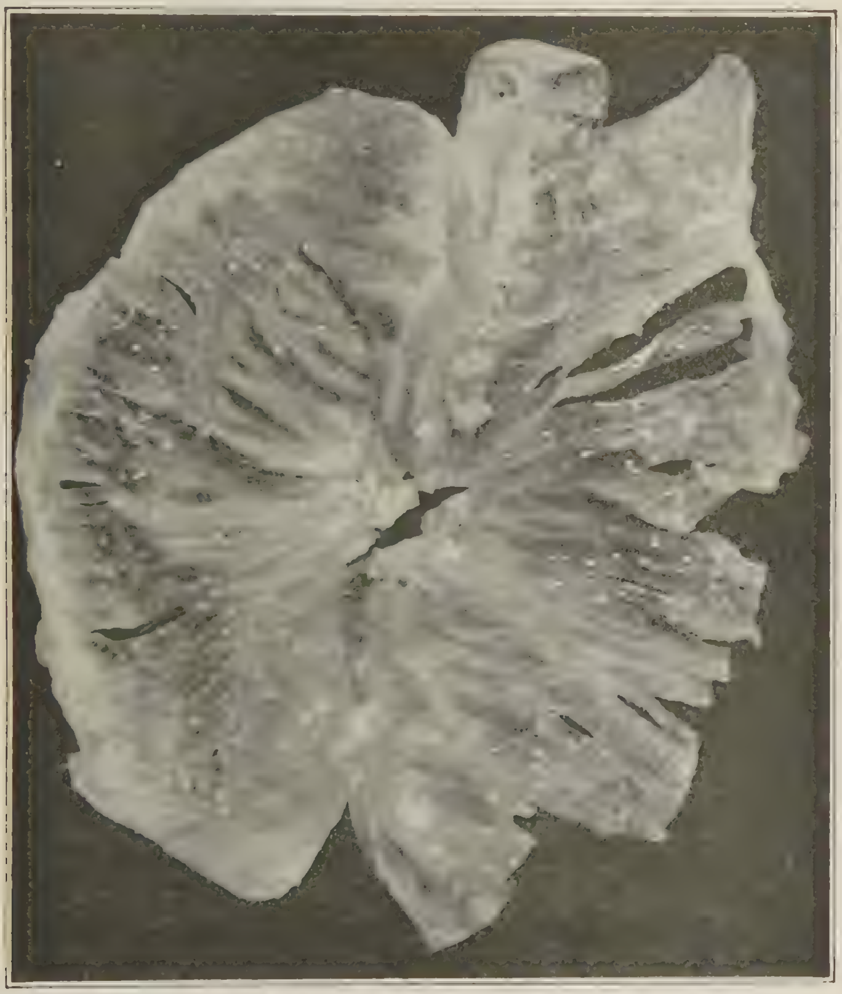

Fig. 154.—Membranes of Navel orange with hesperidin crystals showing as white spots on the surface as result of freezing. (*Photo by C. O. Smith.*)

Other later effects are changes in specific gravity, drying out, etc. (Figs. 155 and 156). When sound and frozen fruits are picked and later compared, it is found that the sound fruit increases while the frozen fruit decreases in specific gravity. In the frozen fruit, the juices of the

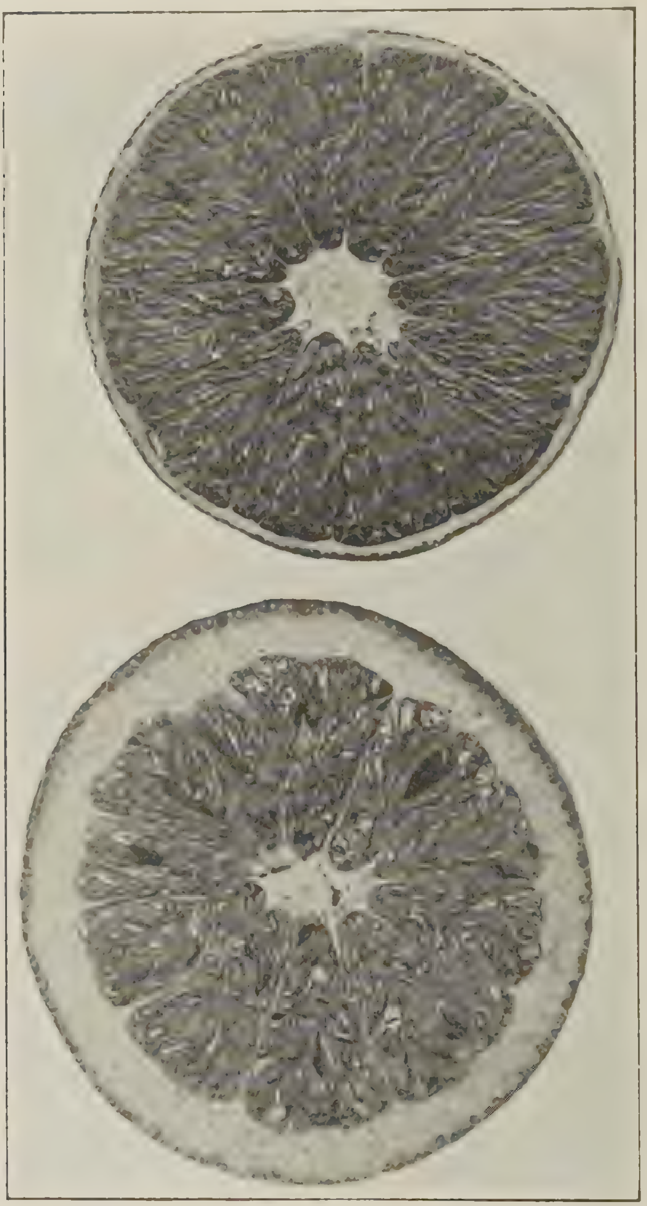

Fig. 155.—Sections of oranges: (*upper*), unfrozen; (*lower*), frozen after storage for two months. The fruits were both $3\frac{1}{16}$ inches in diameter when picked. Illustration natural size. (*After Webber et al* (1919).)

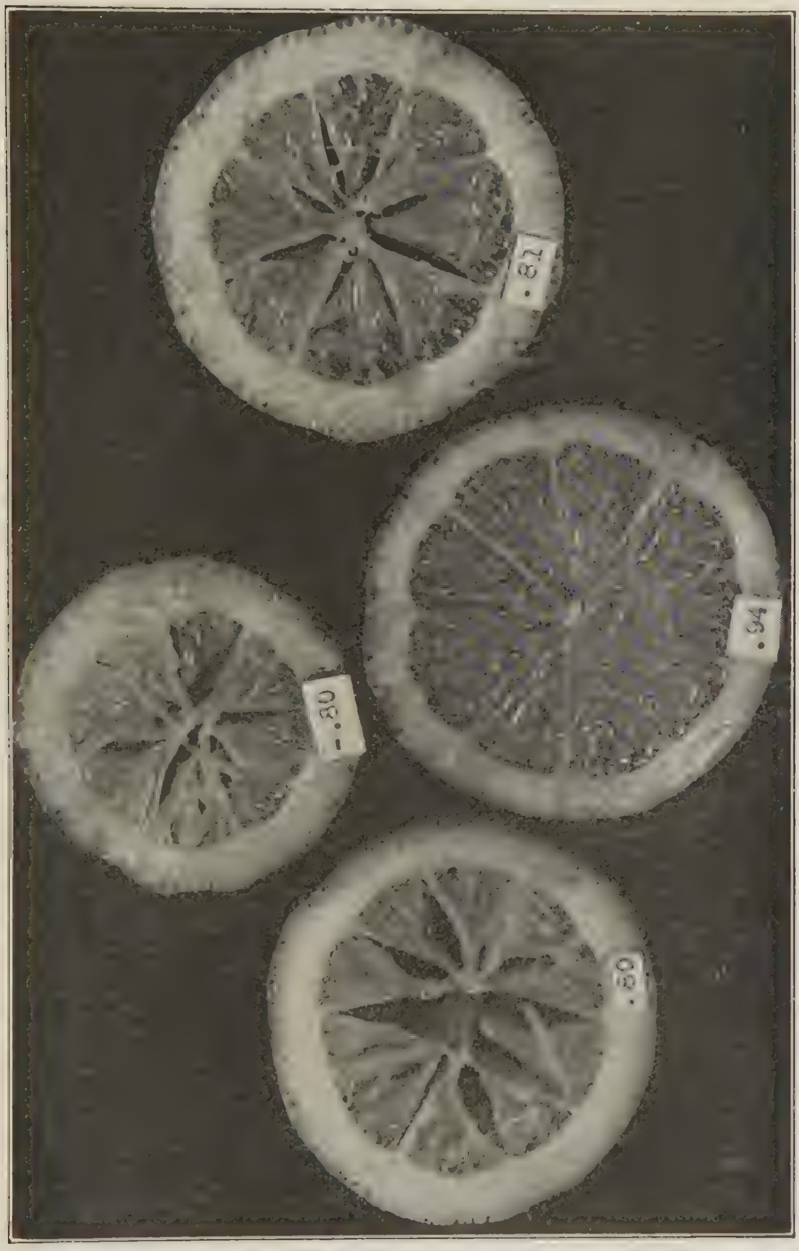

Fig. 156.—Sections of lemon fruits; those with specific gravity of .80 and .81 are badly frozen; others with .94 not frozen. Condition after storage. *(Photo by C. O. Smith.)*

interior pass out into the skin and evaporate without much change in the volume, and the skin appears thick. In the sound fruit, the skin becomes thinner while the interior juices remain practically intact. Frosted oranges sometimes develop a bitter taste which later disappears, and although not harmful to eat, such oranges usually become less rich in flavor. The drying out, granulation or so-called "crystallization" inside the pulp near the stem end, occurring on fruits late in the season, is thought to be influenced by slight freezing or by temperatures low enough to affect the physiology of the fruit without showing any external symptoms. Comparing the more important commercial varieties, lemon fruits are more easily injured by frost than oranges, and oranges a little less than grapefruit. The Eureka variety of lemon in California appears to be slightly more susceptible to frost injury than the Lisbon variety (Webber and others 1919).

Artificial Protection against Frost Injury to Fruit.—The most commonly employed methods of artificial frost protection are running water in the orchard at the time of the frost and orchard heating. Water running in the orchard at the time of frost gives up heat and, if the frost is a light one, may sometimes give considerable protection. If the frost is severe, however, this method cannot be relied upon.

Orchard heating has become an efficient method for protection of Citrus fruits against frost. Various fuels have been used as sources of heat, such as wood, coal and oil. In California the most common and efficient source is crude oil burned in improved types of orchard heaters constructed with a view to rapidity of lighting, ease of regulation, evenness and quickness of heat distribution, etc. With such equipment, hundreds of acres of fruit are now protected from severe injury by frost.[1]

Separation of Frosted Fruit.—Since not all fruits are equally injured by frost on the same trees or in the same orchard, it is desirable to separate the frosted from the sound fruit. This is usually done at the packing house either by water-gravity separators or by picking out the fruit from a floating tank. The gravity separator works on the principle that the frosted fruits are lighter and will, therefore, come up faster, after being dumped into running water, than the sound ones. By a system of screens or partitions, the fruit which has been effected by various degrees of frost may be separated. In the separation of frosted lemons, long soaking tanks are now in common use, which are merely extensions of the tanks into which the fruits are dumped before they pass through the washing machine. As the fruit floats along this soaking tank, the frosted fruit is picked out, not only by its general appearance but by the way it floats on the top of this water. After a little experience, the fruits can be separated very satisfactorily in this way.

---

[1] For details as to frost protection see Cal. Agri. Exp. Sta. Bul. 398 by W. R. Schoonover and R. W. Hodgson, Dec., 1925.

CARPOPTOSIS OR EXCESSIVE FRUIT DROP

Excessive fruit shedding will be considered here under the general heading of carpoptosis, a term first employed by Borg (1900). This shedding may be considered in two phases: (1) the excessive shedding of fruits in the immature stage, and (2) the dropping of fruits as they approach maturity. The former is commonly known in California as "June drop" and the latter is referred to as "fruit drop." A number of factors appear to influence this abnormal shedding of fruits in both phases. Among these are adverse climatic conditions, abnormalities in water and nutritional conditions, insect and fungus injuries. In most cases, two or more of these causal factors may be exerting their influence in conjunction or one follow the other, so that it is often difficult to separate their effects.

Some of the microorganisms often associated with excessive fruit dropping are the two anthracnose fungi, *Glœosporium limetticolum* (p. 284) and *Colletotrichum glœosporioides* (p. 289); the black rot fungus, *Alternaria citri* (p. 393); the melanose and stem-end rot fungus, *Phomopsis citri* (p. 402). Severe attacks of the anthracnose fungi and the melanose fungus in Florida may cause, at times, a considerable part of the very young fruits to be shed. In California, the Alternaria fungus appears to be responsible for only a small part of June drop, the abnormalities of the water and nutritional conditions being more important. As the fruit approaches maturity, this and other fungi often become more conspicuous as factors in shedding. Their attack appears to hasten the changes in the maturity of the fruit and to induce abscission.

History.—Excessive fruit dropping has been an important problem ever since commercial Citrus growing began. The early horticultural literature, as it has to do with Citrus in Florida and California, contains numerous theories and discussions regarding excessive dropping of immature fruit. It has been generally realized that, as in most phenomena of this kind, a complex set of factors is involved. The first serious scientific study of the excessive shedding of immature Citrus fruits was undertaken in 1916 by Coit and Hodgson, who concluded that the "drop" of navel oranges up to the time the fruit is about 1 inch in diameter is closely related to abnormal water relations, especially the daily deficits in the young fruits which serve as a stimulus to abscission. It has also been recognized that nutritional and other conditions have a bearing on setting of the fruits. Under California conditions, as a rule, trees well supplied with nitrogen set a larger number of fruits that are retained to maturity than those lacking nitrogen.

Fruit Drop as Related to ***Alternaria citri.***—A considerable number of dropped navel orange fruits, especially those over 1 inch in diameter, have been found to be infected at the navel cavity with the fungus, *Alternaria citri.* According to Coit and Hodgson (1919), the infection takes place when the fruit is quite small, probably soon after the style is shed, through the cracks and imperfections in the proliferations of the navel. The fungus, being a weak parasite, usually remains quiescent or nearly so during the early growing period of the fruit, but as the fruit approaches maturity the fungus becomes active and exerts a stimulus resulting in abscission. In some seasons, however, the fungus appears to be capable of producing sufficient stimulus to cause abscission of a certain small proportion also of the young green fruit. This is frequently accompanied by the formation of gum in the navel cavity.

The Alternaria fungus appears to be universally present in the orchards under California conditions. Coit and Hodgson found 89 per cent of stigmas with this fungus upon them in the interior valleys and 76 per cent in the coast localities during May and June, 1917. It was also determined by exposure of agar plates that the air generally carried spores of the Alternaria fungus, as was found in 78 per cent of five-minute exposures in the interior valleys and in 63 per cent of exposures in localities near the coast (Coit and Hodgson 1918, 1919).

Since the presence of the fungus is so general, the infection and development in the fruit to a degree sufficient to bring on the stimulus to abscission are probably dependent on slight growth cracks or certain physiological conditions of the tissue. Maturity of tissue and manner of navel formation are probably important factors. It is a general observation that more fruits which are about to mature are likely to be infected in orchards located in the interior than in those in the coast sections. One reason is thought to be the fact that the average configuration of the navel from interior sections tends to be more irregular, jagged and rough than of those near the coast. This irregular abnormal growth of the navel probably produces rupturing of tissues that encourages the subsequent invasion of Alternaria. If, along with this, a late rainy season occurs, the percentage of Alternaria is likely to be increased. For example, at Redding, Cal., a navel orange orchard showed 50 per cent of the fruit infected with black rot at maturity (Fawcett 1922*c*).

The Nature of June Drop.—With the Washington Navel orange, it is the excessive amount of shedding of young fruits rather than normal or expected "drop" that constitutes what is strictly included in the term "June drop." In a study of the whole process of shedding, Hodgson (1917) and Coit and Hodgson (1919) have brought out the following interesting facts and observations:

1. In many of the flowers, the pistils show varying degrees of degeneration. The shedding of flowers is largely confined to these.

2. The majority of the young oranges are shed while still alive and actively functioning, even when not affected with fungi or infested with insects.

3. The period of maximum shedding takes place when young fruits are from ⅕ to ⅘ inch (0.5 to 2 centimeters) in diameter.

4. At first the point of abscission is always at the base of the pedicel, but after the fruit is about ⅖ inch (1 centimeter) in diameter, it is usually at the base of the ovary. At this time, strengthening tissue at the base of the pedicel prevents the pedicel from falling, although abscission may extend through the cortex at that point. Strengthening tissue may sometimes also form at the base of the ovary and thus prevent the fall of the larger fruit, even after it is physiologically cut off from water or nutrients. Some of these dry up and remain hanging to the tree.

5. Under field conditions, abscission is usually complete within five to eight days after the application of the stimulus. The stimulus believed to be responsible for abscission is the occurrence of "periods of excessively high atmospheric temperature or extremely low atmospheric humidity or, what frequently happens, a combination of the two." Soon after the application of the stimulus, but several days before separation, the larger fruits lose their luster and take on a lighter green color. In exposed fruit, the yellow color is deeper around the apex.

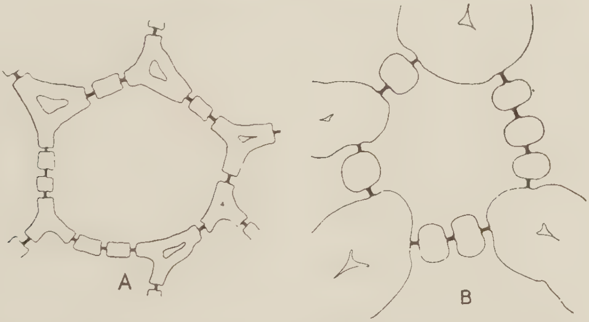

Fig. 157.—Cortical cell from the abscission zone at the base of the petiole of Washington Naval orange. A, showing a highly magnified view of the cell prior to the application of a stimulus leading to abscission of the leaf, relatively thick walls and simple pits are shown; B, showing the cell at an early stage of the abscission process as the result of swelling and gelatinization. (*After Hodgson* (1918).)

6. The first microscopic indication of abscission is a marked swelling and gelatinization of the cell walls, the swelling amounting to two or three times the original thickness (Fig. 157). This swelling is followed by dissolution of the gelatinous walls, thus freeing the cells. There is, therefore, dissolution of the middle lamellæ of the abscission-zone cells by hydrolysis, with subsequent separation.

Water Relation and June Drop.—After considering the various conditions responsible for the excessive shedding, known as June drop, of Washington Navel orange fruit in the interior valleys of California, Coit and Hodgson (1919) have concluded, as a result of their investigations, that the water deficit is the most important in that period or phase of the shedding which occurs before the fruit is 1 inch in diameter. The navel orange is apparently quicker to respond to the stimulus of water deficit by abscission of fruit than many other varieties. Under the climatic conditions of the interior valleys, with low humidity, high temperatures and extreme fluctuations of temperatures during the growing period, the navel orange is not adapted to withstand the heavy water loss. Even when the roots have access to abundant water in the soil, they have difficulty in supplying sufficient amounts to the leaves and fruit.

Other Factors in Relation to June Drop.—That there are other contributing factors besides water deficit and fungus attack is, of course, recognized. One of these is nutrition. There appears to be a close relationship between water deficit and lack of available nitrogen. If the two go hand in hand, shedding increases. There is also some evidence to indicate that the presence of sufficient nitrates in the soil solution protects the tree to a degree against abnormal moisture relations. Trees that show nitrogen starvation may bloom heavily but set few if any fruit.

Under certain conditions of sandy or light soils, as in Florida, the opposite extreme, or too much nitrogen, is thought to bring on malnutrition in the form of exanthema resulting in failure to set fruit. Lack of adequate calcium also has been shown by Reed and Haas (1923*c*) to cause severe shedding of leaves, and this influence is probably also extended to the fruits.

Suggestions for Control.—For that part of the "fruit drop" due to *Alternaria citri*, no practical prevention can be suggested. Spraying tests that have so far been carried out do not indicate sufficient control to warrant the cost (see p. 393). For that part of the June drop due to water deficit, nutritional or other conditions, certain general suggestions may be given. The most practical means of control at the present time under California conditions appears to be the use of nitrogenous fertilizers in such a way that there will be an ample supply of nitrogen available to the roots at the time of blooming and setting of the fruit. Extremes in nitrogen fertilizing, however, may need to be avoided, especially on light sandy types of soil. The adverse climatic conditions can be only partially alleviated. The effect of drying winds during periods of low humidity may be partially overcome by suitable windbreaks. Systems of overhead sprinkling or devices for keeping the air more humid at periods of stress might be suggested. Keeping the soil at optimum moisture conditions consistent with good root development is also important in times of low air humidity. Keeping the soil well supplied with bulky organic materials that improve the water-holding capacity of the soil is another means of avoiding some of the water deficiency.

For future planting in districts especially subject to June drop, Coit and Hodgson suggest the advisability of looking toward finding a variety or mutation which will be more resistant to the adverse conditions that tend to produce excessive abscission and drop of fruit.

FRUIT GUMMING

Gum formation within the fruit or at its surface frequently occurs, taking various forms and being due to various causes.

Gum at the navel cavity of green orange fruits of various sizes may be due to invasion of Alternaria or other organisms at an early stage. At later stages gum may be seen on split places where the fruit has been burst open by too great turgor or internal pressure. Defective development of a segment of a fruit may also give rise to gum formation. Gum may sometimes form, under certain conditions, at the surface of small green fruits following fumigation. Gum may also form as a result of insect injuries, such as Tortrix holes, grasshopper bites, etc.

Earle and Rogers (1915) have called attentioh to a gumming of immature grapefruit in Cuba. When the fruit is an inch or more in diameter, dark, water-soaked regions form in the thick inner rind, gum oozes out from these regions to the surface, and dark-colored, irregular spots appear on the skin above the gummy places. Such gumming of the fruit is usually from trees in poor condition because of too wet soil. This form of gumming of the fruit is also encountered in Florida. No organisms have been found associated with the disease in its early stages. The anthracnose fungus develops rapidly on the spots later.

Gum may also form internally in connection with various diseases and as a result of various external and internal effects. In exanthema, one of the symptoms is formation of clear gum at the center of the fruit in the angles of the divisions or segments. In severe cases of Citrus canker and other diseases, droplets of gum sometimes exude on the surfaces of the fruit. In internal decline, there takes place frequently in lemon fruits a gummy degeneration at the stylar end. Putterill (1923) mentions a gum formation in sour-orange fruits, observed in South Africa. Internal fruit gumming has been observed in fruits slightly affected with frost after repair of tissue begins.

CHAPTER XVIII

EXTERNAL SPOTS, MARKINGS AND ERUPTIONS

ADUSTIOSIS OR RED BLOTCH

Red blotch is an external staining or marking of lemon fruits of unknown cause developing only after the fruit is picked. Its appearance is often suggestive of a scald, from which the term adustiosis is derived. Like peteca, it develops usually in fruit picked in the cold, wet season. Adustiosis or red blotch appears to be a physiological breakdown of external layers of tissue and is not, so far as known, caused by any microorganism. In severe form, it has frequently been referred to as "red rot," but is not a "rot" in the usual sense.

History and Distribution.—Red blotch has been known for a number of years in California (R. E. and E. H. Smith 1911), where it has become very troublesome in lemon storage houses during unusually wet winter seasons or in wet seasons a year after a severe frost. In the winter after the freeze of 1913, the disease was very severe. As far as known, it has not been reported outside of California.

Symptoms.—Red blotch starts as a slight, superficial, reddish-brown discoloration of the surface of the fruit in storage. Under the hand lens, this stain may appear as if made up of numerous very fine dots close together on, or in the surface of, the cuticle. It may be at first light cinnamon brown (Ridgway's 1912, cinnamon to sayal brown) in color with the yellow showing through or between. Later, a more continuous stain occurs, remaining very superficial for some time, without any visible collapse of the oil glands (Fig. 158A, B). Finally, some surface cells, mostly between the oil glands, begin to collapse and become dry and hard. Only in severe cases, after one-half to two-thirds of the fruit is involved, is there a drying, hardening and staining of a few deeper layers of the rind, with the development of a continuous color of deep salmon brown to chestnut brown (carob brown to chestnut brown), going finally into chocolate, dark brown or buff brown (chocolate, burnt umber or vandyke brown of Ridgway).

Contributing Conditions.—Adustiosis or red blotch develops in storage under much the same weather and seasonal conditions as does peteca and membranosis. It appears to be emphasized or aggravated by forced curing of lemons either by the use of ethylene gas or exhaust from kerosene stoves, but may also occur with normal curing. It also appears to be aggravated by lack of ventilation in storage. Usually, though not

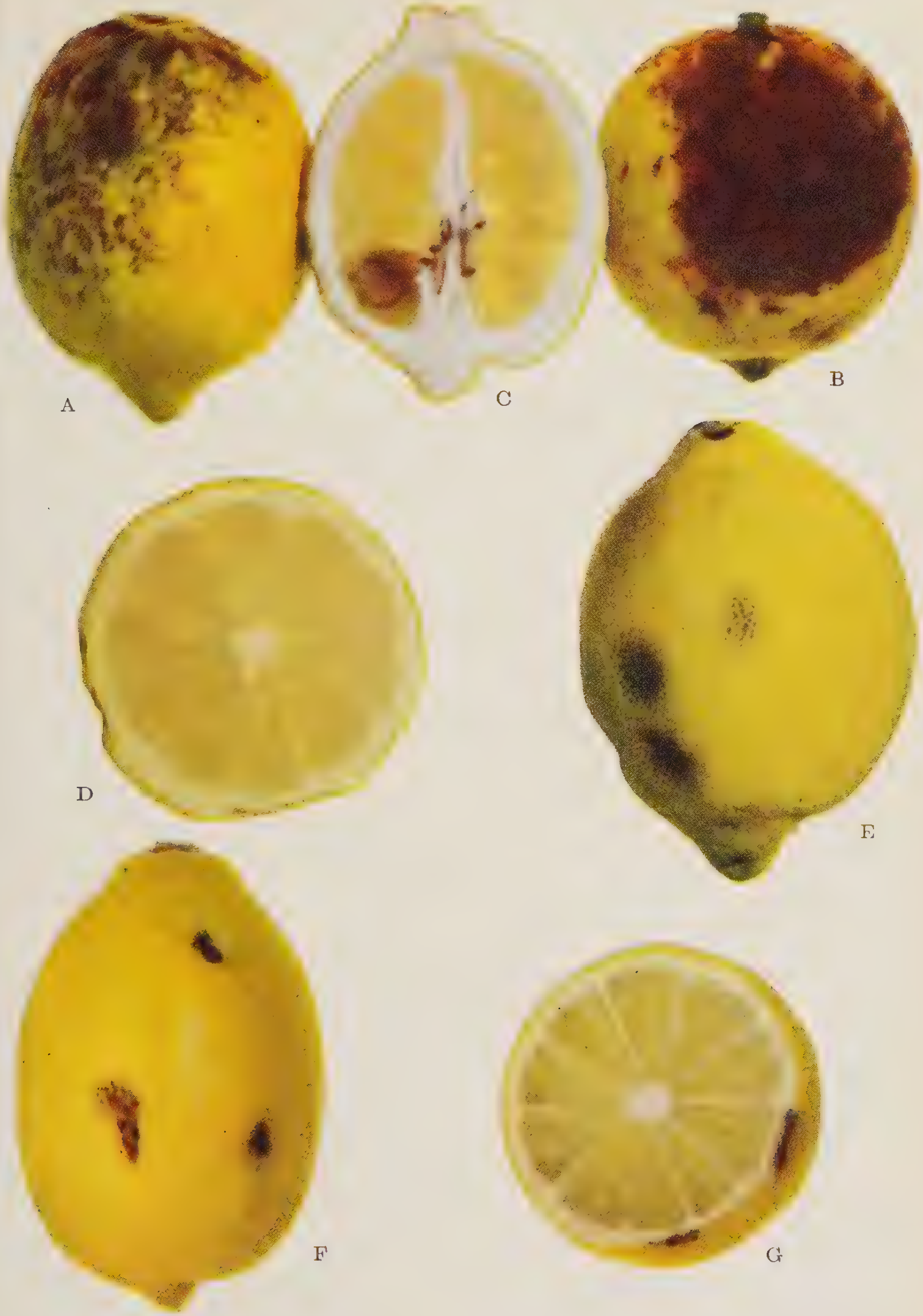

FIG. 158.—Red blotch, membranosis, peteca and black pit on lemons. A and B, Red blotch or adustiosis stain on surface. C, Membranosis stain on the membranes in the interior. D and E, Peteca spots. F and G, Black pit or citro-necrosis spots in the rind due to *Pseudomonas citriputeale*. About two-thirds natural size.

(*Facing page* 440)

always, it is accompanied by membranosis. If it is brought on rapidly during forced coloring, membranosis may not develop with it, but if it comes on more slowly during normal curing, the staining inside is a very usual accompaniment. Sometimes the central core and membranes may be very badly stained in nearly every fruit showing the red blotch, while at other times the interior may be normal with the red blotch quite prominent on the surface.

Control.—As in peteca, a lack of definite understanding as to the cause makes it possible to suggest only the most general and indirect method of prevention. The growing of strong vigorous trees protected from severe shocks, extremes of temperature, wind, water, etc., serves to produce resistant fruit. Being an external breakdown, the affected fruits may be readily seen and eliminated in packing the fruit after storage. While red blotch does not rot the fruit itself, it opens up the way for blue and green mold, anthracnose or other rots which in a secondary way cause much loss in storage. Fruit subject to red blotch should be inspected frequently, and the badly affected fruits culled out to prevent the start of decay.

PETECA

Peteca is a peculiar spot of unknown cause occurring, in California, in lemon fruits in storage[1] during the cool, moist seasons of late autumn, winter or early spring. It is also said to occur in southern Europe and was seen on Italian lemons in storage in the United States in 1924. It has been known by growers in California ever since the lemon industry started. The name appears to have been first adopted by R. E. and E. H. Smith (1911).

Symptoms.—Peteca is characterized by a deep pitting due to the sinking of the surface of the rind, usually some time after the fruit is picked (Fig. 158D, E). The surface cells, at first even in the depressions, are normal, without any sign of abrasion or mechanical injury, but the tissue underneath the pits in the inner peel are dry and shrunken and may be white or slightly discolored (Fig. 158D, E). If white, the color of the pits may not be different from the remainder of the rind, but if discolored, the depressions appear darker because of the semitransparency of the normal cells covering the affected cells (Fig. 159). If uncolored pits have access to water, as in soaking, the rind straightens out again, and it is difficult to tell where the pits have been.

The cells of a portion of the inner rind appear to be the first to collapse and dry out, after which the outer portion of the rind which is still intact sinks down. Preceding this sinking of the surface of the rind, the dry regions of tissue in the inner peel may be found by cutting off the outer portion. These later become the places where the deep pits form. These surface cells may remain normal in mild cases or may later collapse and dry out, also making the bottom of the pit dark and discolored. The pits, being areas of weakness, may also open the way to infection by organisms.

---

[1] Occasionally it develops before the fruit is picked.

Peteca spots have close resemblances to early stages of black pit, with the difference that the latter almost invariably has a thorn prick or some slight abrasion into which the black-pit bacterium has entered. It was at one time thought possible that peteca was an arrested stage of black pit. This seemed possible because the black-pit organism often dies out quickly after it has produced black-pit spots. Attempts, how-

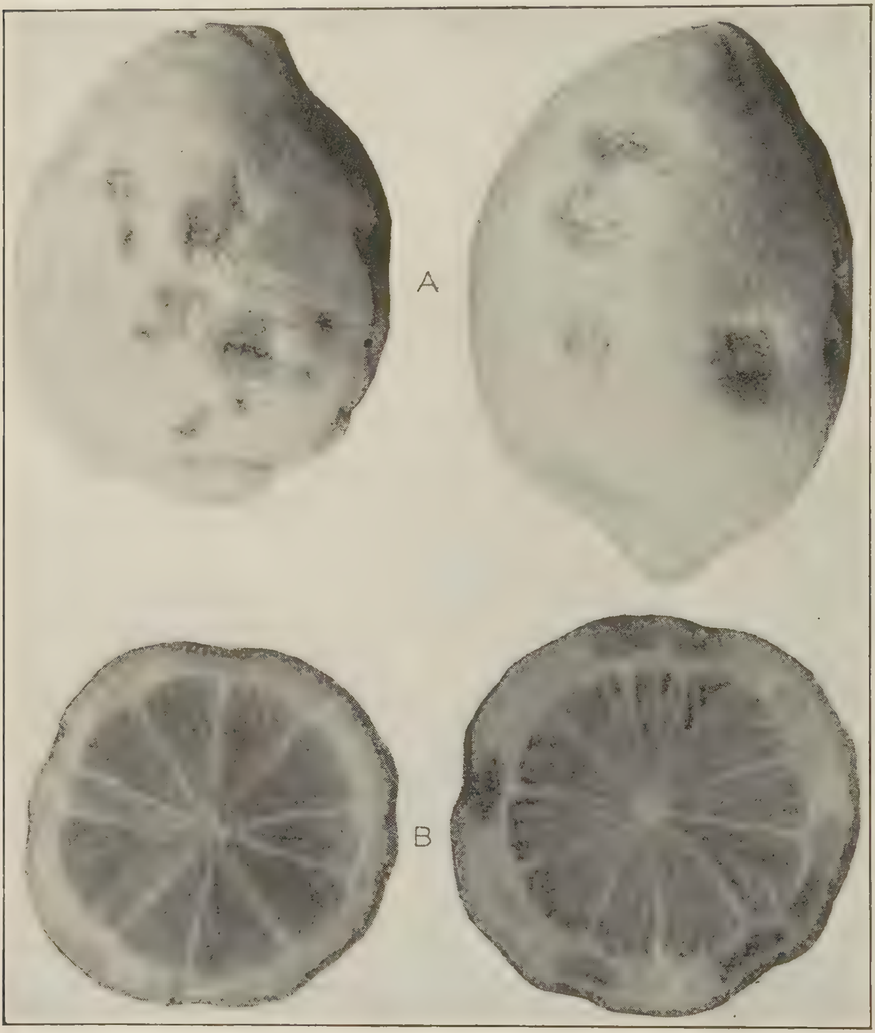

Fig. 159.—Peteca on lemon fruits. A, showing sunken spots on surface; B, showing how rind is affected within.

ever, to isolate the organism from beginning stages of peteca or to reproduce the typical peteca spots by inoculation have failed.

Control.—Only the most general suggestions can be given regarding control. Nothing definite is yet known as to the cause or means of preventing peteca. Fortunately, it is only occasionally a serious trouble in storage, and then only in unusually moist, cool seasons. Often it accompanies or is produced by the same set of conditions that bring on membranosis of the interior and adustiosis or red blotch of the exterior. It is probably emphasized by forced curing and by lack of ventilation. It appears to be more prevalent in fruits from certain orchards than from others nearby in the same district. Certain unfavorable conditions in the orchard appear to have an influence in rendering the fruit susceptible. Methods of raising sound fruit should, therefore, be employed. Then, if peteca becomes serious in storage, the affected fruit will need to be culled out, or if only slightly affected, some of it may be put into the lowest grades.

ALBEDO BROWNING

This takes the form of a discoloration of the white spongy portion of the peel which is known as albedo. This often extends to a part or sometimes the greater portion of the peel of the lemon fruit. The surface of the rind may appear normal, except for a slightly darker or "dead" color, which arises from the inner discolored portion showing through the thin oil-bearing portion of the rind. When the rind is cut into, what is usually the white inner albedo portion is brown and sometimes shows a sort of gummy consistency. It is usually a dull brown (Ridgway's sayal brown) in color. It develops on fruit in storage and is more prevalent on fruit that has been put into storage while very dark green. Nothing is definitely known regarding the contributing conditions, cause or control of this albedo browning, although it is suspected to be connected in some way with abnormal respiration.

BLACK-PIT FORM OF CITRO-NECROSIS

This is a spot or pit due to the bacterium, *Bacterium citriputeale*,[1] which enters at thorn pricks or other injuries to the skin during wet weather. The black-pit form of citro-necrosis is most noticeable on lemon fruits, but may also occasionally be found on oranges or other commercial varieties. The same bacterium also produces on leaves and twigs lesions known as Citrus blast, described on page 293.

History and Distribution.—The black-pit or citro-necrosis spots on Citrus fruits were first described by C. O. Smith (1913), who also showed by cultures and inoculation experiments that the disease was due to the bacterium, *B. citriputeale.* Later Fawcett in 1920 (Fawcett, Horne and Camp 1921, 1923) found that Citrus blast for which Lee (1917) had worked out the causative agent was also due to the same organism. The black pit on the fruit, as well as Citrus blast on the leaves and twigs,

---

[1] This would be designated *Phytomonas citriputeale* according to the new nomenclature of the American Association of Bacteriologists.

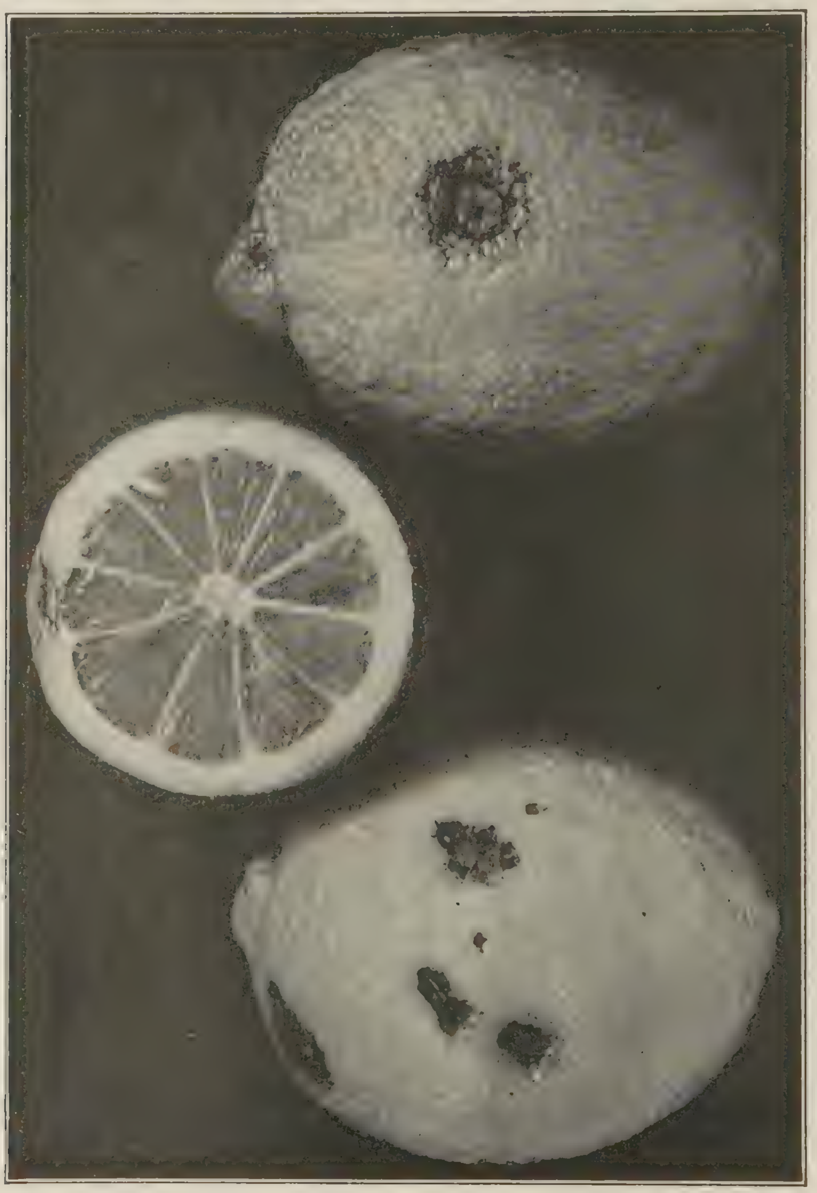

FIG. 160.—Black pit form of citro-necrosis on lemons showing spots started from slight scratches or injuries.

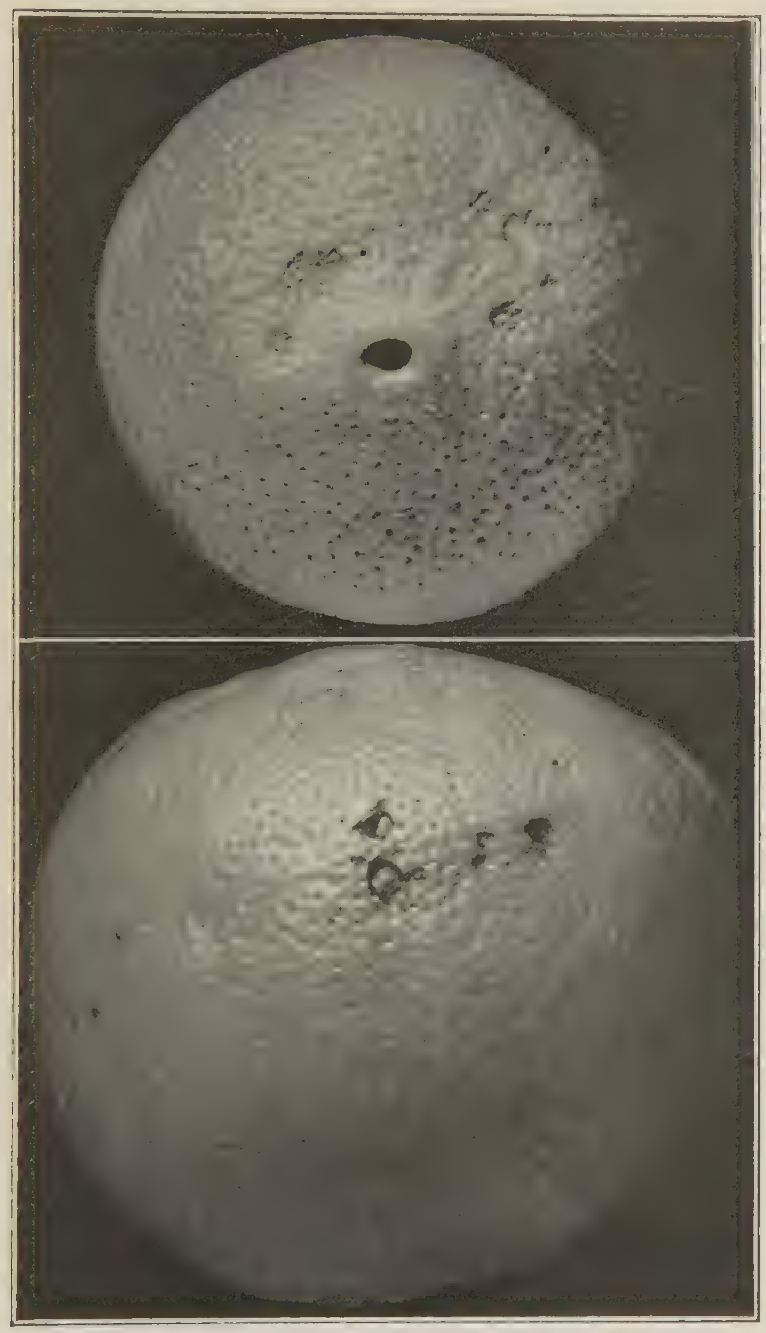

FIG. 161.—Black pit form of citro-necrosis on, (*upper*) Navel orange, (*lower*), grapefruit about natural size.

has been reported by Savastano (1923) and Fawcett (1925*b*) in Sicily and Italy, where it is known as "mal secco." The disease has recently been reported in South Australia and Victoria by H. K. Lewcock (Phyto. **16**: 18, 1926). Spots of a similar kind due to a different bacterium have been described in South Africa by Doidge (1917) (see p. 450).

Symptoms.—As "black pit," the disease manifests itself on the fruit, especially in lemons, as sunken black spots (Figs. 158 F, G and 160). As these develop, they change from a light brown to dark brown and then to black. The inner white part of the peel is also affected. There is a collapse of the tissue, which finally becomes light brown tingeing to reddish brown in color. The size of these spots is dependent upon the conditions of moisture and temperature under which they develop. On lemons, they are mostly from ¼ to ½ inch in diameter, but may attain a size of ¾ inch. If the spots occur close together, they may be smaller. These black-pit spots may also occur on oranges and grapefruit (Fig. 161), but are usually not so common nor so deep as upon lemon fruits. As in Citrus blast, the black-pit spots usually result from injuries. A speckling of lemons and oranges in moist seasons or following moist weather is suspected of being due to the same organism. It consists of very small, brown to nearly black, slightly sunken specks or pits close together on one side, or over nearly the entire surface (Fig. 162B). As observed on oranges, the speckling consisted of spots ranging in size from minute specks to specks 1 millimeter in diameter, thickly scattered over one portion of the side of the fruit (Fig. 162A). The skin between the specks was normal in color. The specks possessed steep definite sides but not a great total depth. The effect was confined to only a few layers of cells.

Susceptibility of Species and Varieties.—A large series of inoculations on many varieties of Citrus fruits was made in January, 1924, at the California Citrus Experiment Station with the following results: Punctures were made with a needle through a drop of water containing the bacteria and the fruits enclosed in paraffined sacks. The spots first showed as a water-soaked area about the puncture, and in a few days there was a sinking of the tissue at first resembling peteca spots but later turning brown and on some varieties still later almost black. The spots soon came to a definite limit. The affected tissue was considerably greater in area in the inner rind than on the surface. On fruits with rather thick peel, the spots tended to be deeply sunken, but on those with thinner peel they were less sunken. On fruits on the tree, the spots rarely developed very large in size. They came to their maximum limit in about five to ten days. Judging from the size and rapidity of development of spots in our experiment, lemon varieties of fruits appeared to be the most susceptible and the mandarin group the most resistant, although slightly susceptible. Kumquats appeared to be equally resistant. Spots on lemons which averaged about 2 to 3 millimeters in diameter in three days were at their maximum of 6 millimeters in nine days on the surface and about 7 to 8 millimeters in diameter in the inner skin. The mandarin group, except Dancy tangerine, showed no effect in three days and only a maximum of 1 to 2 millimeters in nine days. Of the lemons in the experiment, the Lisbon, Villa Franca and Eureka were about equal to each other, but the rough lemon less susceptible. Of the mandarin group, the King and Clementine mandarin were

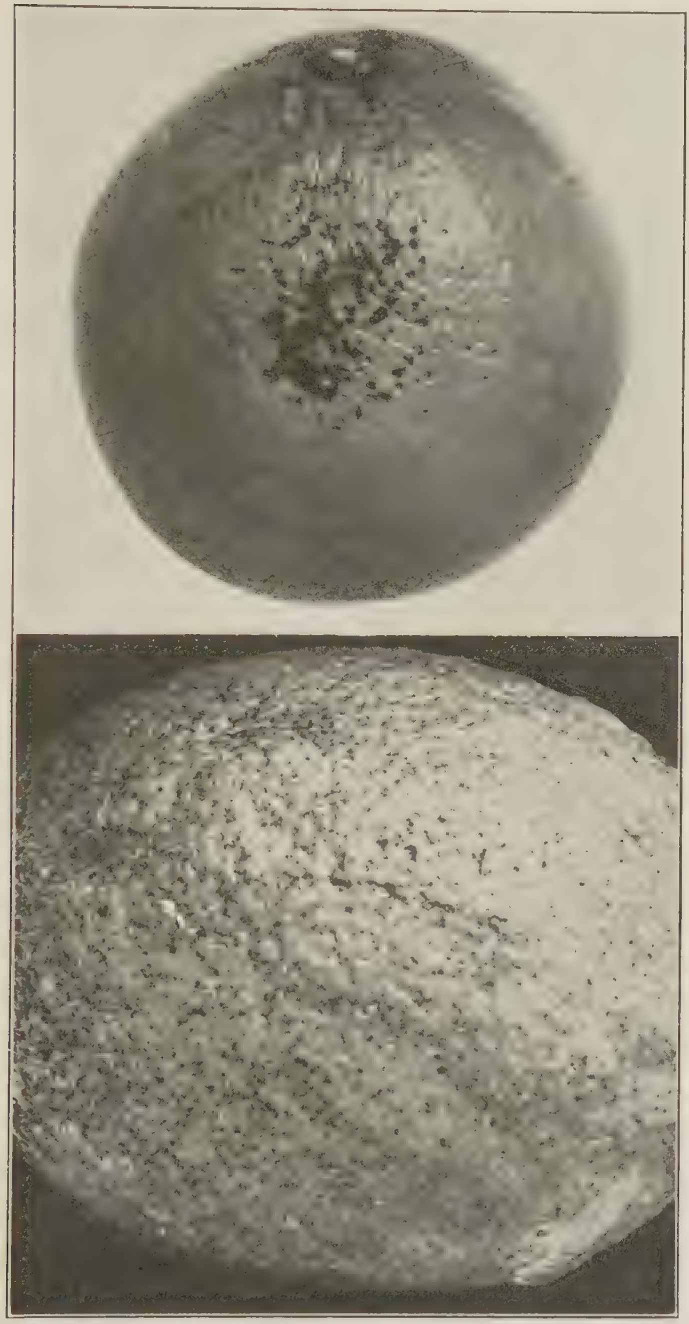

Fig. 162.—Speckling or pitting thought to be due to the black pit organism *Bacterium citriputeale:* (*upper*), on Washington Navel orange; (*lower*), on lemon.

nearly resistant, the Dancy tangerine a little less resistant and the Satsuma orange also resistant. The sweet-orange group was fairly susceptible. Navel, Valencia and the varieties known as Parson's Brown and Pineapple orange and Lue Gim Gong were all about equal to each other. The pummelo group, represented by Marsh seedless, McCarty, Duncan and Triumph, were only a little less susceptible than the sweet oranges. The lime fruits represented by the Mexican, Tahiti and Rangpur limes appeared to be intermediate, but the "Kusaie" lime was about equal to the grapefruit varieties. In the citrons, the spots were slow in development, but finally became as large as those in the grapefruit. The Sampson tangelo (tangerine × pummelo) appeared to be intermediate in susceptibility.

Table 8.—Color of Spots on the Surface and in the Inner Rind of Fruits Nine Days after Inoculation with the Black Pit Organism
(Colors per Ridgway 1912)

	Color on surface	Color inner skin
Lemon	Natal brown or benzo brown (later black)	Light drab, cinnamon drab and wood brown
Sweet orange	Mars yellow, amber brown, Sanford brown or antique brown (later mummy brown)	Very slight or no discoloration
Grapefruit	Sorghum brown to antique brown (later sepia to warm sepia)	Fawn to antique brown (later sepia)
Tangelo	Seal brown to raw sienna (later mummy brown)	
Rangpur lime	Sudan brown	

That the organism appears to die gradually in the spots after they reach their development is shown by culture tests. In nine days after inoculation, the organism was readily recovered from most of the spots. The fruits were then picked and kept from drying out in the laboratory in paraffined sacks. Twenty days after inoculation, the organism was recovered from only part of the spots on oranges and grapefruit, but in thirty days the organism was no longer recovered from the spots in our tests.

Contributing Conditions.—While the black-pit form of the disease on fruit depends, in general, on the same special set of conditions as the blast on leaves and twigs (p. 297), it is not quite so limited in its occurrence as is the occurrence of the blast lesions. In southern California black pit may develop on fruit, especially lemons, in seasons and under conditions of moisture, temperature, etc., where and when no blast will be evident. The duration period for air moisture does not need to be so prolonged for black pit as for blast, though both lesions are due to the same organism. The infection occurs as in blast in the cool, moist period of winter and early spring. It depends on injuries, such as thorn pricks, hail marks, insect punctures or other abrasions, while the fruit is wet and still on the tree. Wind storms with rain, followed by cool moist atmosphere, supply an ideal set of conditions for infection and development. Hail following a moist period is a suitable condition. The wind in whipping about the fruit-laden branches causes the skin of the fruit to be punctured, scratched and broken, and the causal bacteria appear to be disseminated especially well by driving rains.

The effect of different temperatures on the development of spots on yellow lemon fruits is indicated by the following experiment (Fawcett, Horne and Camp 1923):

Inoculations were made by transferring a 2-millimeter loop full of bouillon culture and puncturing the surface of the rind through this drop. The fruits were then placed in moist chambers at different temperatures. The average sizes of spots developing in three and in five days, respectively, are shown in the following table.

TABLE 9.—SIZE OF BLACK-PIT LESIONS DEVELOPING AT DIFFERENT TEMPERATURES

(Average of about Twenty-four Punctures on Four Yellow Lemon Fruits in Each Temperature)

	Temperature						
Degrees Centigrade	8.5	12.5	17	20.5	25	28.5	33.5
Degrees Fahrenheit	47	54.5	62.6	69	77	83.4	92.5
Size of lesions, in millimeters, after three days	2.0	3.5	6.6	6.6	6.3	3.3	3.1
Size of lesions, in millimeters, after five days	2.3	5.1	8.0	6.6	6.3	3.3	3.1

At temperatures 17, 20.5 and 25°C. (62.6, 69 and 77°F.) the spots averaged about equal as to diameter on the third day. They were more sunken at the highest temperature. In five days, the spots developing at 17°C. (62.6°F.) were decidedly larger than at any other temperature. Those developing at 20.5°C. (69°F.) or above did not increase after the third day. Those at 33.5°C. (92.5°F.) were not typical, deep-seated spots and probably developed rapidly previous to the death of the organism. Those at 28.5°C. (83.4°F.) did not enlarge after the second day.

It is here seen that spots develop fairly well from inoculations at temperatures from about 55 to 75°F., the most suitable temperature being about 63°F., and that as high as about 83°F. and above checks the development of spots.

Control.—Any practical methods for the control of the black-pit form of citro-necrosis where it is severe on the fruit should follow the same lines as that given for the blast form on leaves and twigs (p. 302). The black pit, however, from a practical point of view is only a minor trouble under California conditions. In northern California, the principal crop, navel oranges, is harvested before the season for greatest injury from black pit. In southern California, black pit is occasionally troublesome on lemon fruits in the moister sections following heavy winter winds with rain. It has not, however, been severe enough to call for special control measures in the orchards. Any measure such as windbreaks, or other means of preventing injury to the fruit in winter, would largely control it. Fruit badly spotted may open the way for other kinds of decay and should, of course, be discarded in the packing house. Small spots, however, that have run their course and are dry, hard and firm may not necessarily allow the entrance of other decay so long as the fruit is dry.

BACTERIAL SPOT OF SOUTH AFRICA

In South Africa, dark sunken spots on fruit and lesions on stems occur which are similar to black pit and blast in California but are due to a different bacterium, *Bacillus citrimaculans*. According to E. M. Doidge, who described the disease in 1917, it is confined to the valleys of the Groot and Klein Drankenstein and the Berk River Valley in the Western Province.

The disease was found occurring naturally on lemons, tangerine and mandarin oranges and navel oranges. The spots on fruit were induced by inoculations in the above Citrus varieties and also in shaddock, grapefruit, citron and sour and sweet limes. Doidge (1917) reports that the Seville orange is the only variety so far found to be resistant.

Symptoms.—The sunken, dark-colored spots "are either leathery in texture or else quite hard." On lemon fruits, they may vary in size from about ⅛ to ⅖ inch (3 to 10 millimeters) in diameter and are depressed 1 to 2 millimeters below the surface of the healthy rind (Fig. 163). Although the spots tend to be circular in outline, the coalescing of several spots may result in the formation of an irregular large blotch. As in black pit in California, a close examination usually reveals an injury at the center of the spots. At first, spots take on shades of yellow, yellowish brown and pinkish brown (maize yellow with buckthorn brown center or chamois color with margin and center of mikado brown); older spots varying from "argus brown through light seal brown to blackish brown" (per Ridgway 1912). The penetration inward may be, in some cases, only halfway through the rind and, in others, through the rind into the pulp. In severe cases, the pulp is cinnamon brown in color inward for a short distance only.

On oranges, the spots average ⅘ to 1⅕ inches (20 to 30 millimeters) in diameter and are less sunken than on lemons. The color is buckthorn brown to dresden brown. On tangerines and mandarins, the disease is especially severe. The spots, round to irregular (Fig. 163), are from 1/25 to 1 inch (1 to 25 millimeters) in diameter, slightly sunken and varying in color from something between pinkish brown or light cinnamon brown to blackish brown (mikado and sayal brown to blackish brown). In large spots from thorn pricks, the effect penetrates through the skin into the pulp, giving it a peculiar taste and odor.

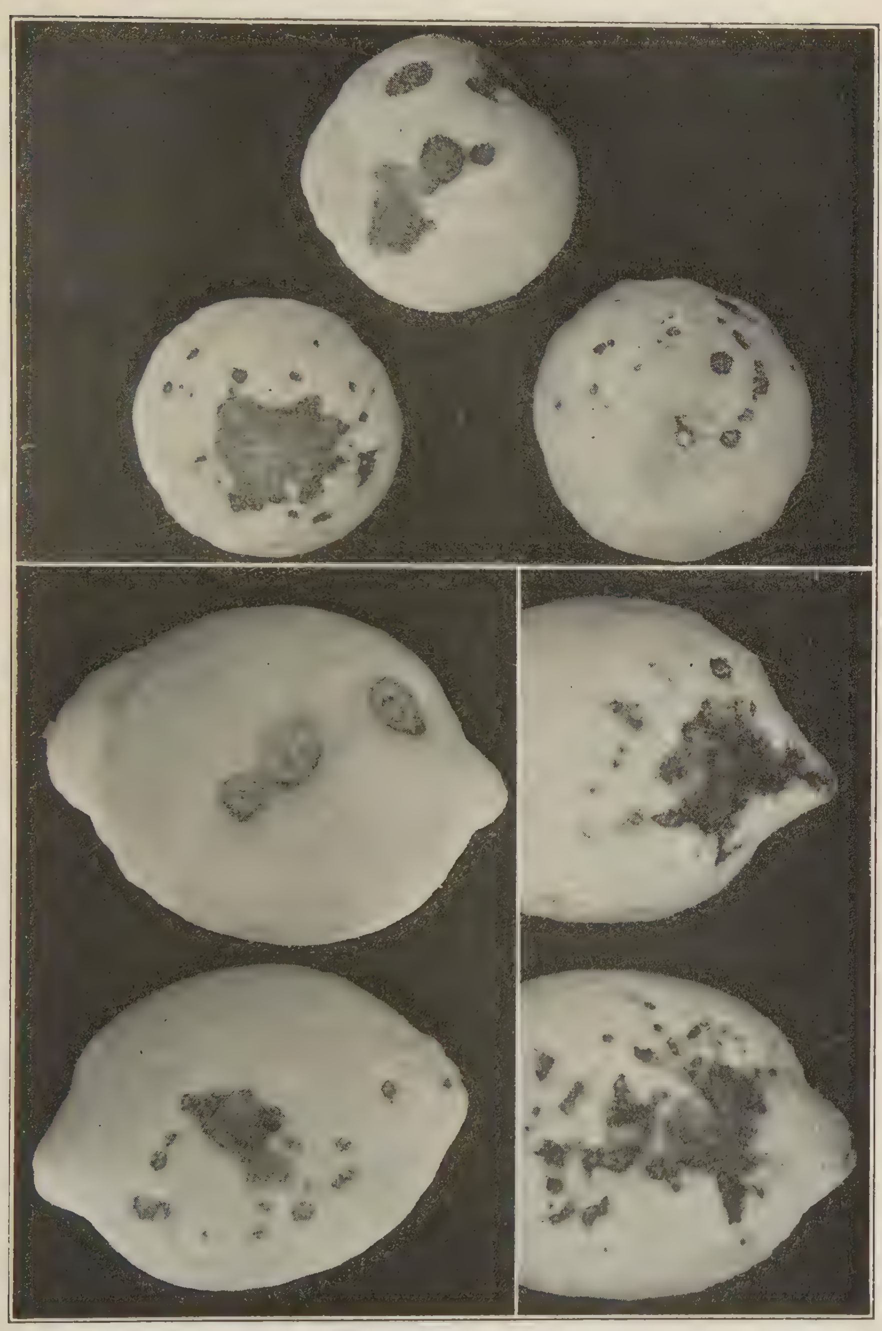

FIG. 163.—Bacterial spot of South Africa. Above, natural infection on three mandarin oranges ("naartjes"). Below, spots on four lemons. (*Photos contributed by E. M. Doidge.*) (*After Doidge* (1917).)

This disease also affects the branches and leaves. Like the Citrus blast, it attacks the stem around the leaf bases.

> An area of about ¼ to ⅖ inch (6 to 10 millimeters) in diameter becomes water soaked in appearance, the petiole becomes involved and sometimes the basal part of the leaf, and the leaf falls.

Some infected areas may become ⅘ inch long and extend halfway round the stem. The central portion later loses its water-soaked appearance and assumes a chestnut-brown to olive-brown, slightly sunken appearance. Only a slightly yellow color appears on the surface of the woody cylinder, and, toward the end of the season, gum may ooze from the severed leaf bases.

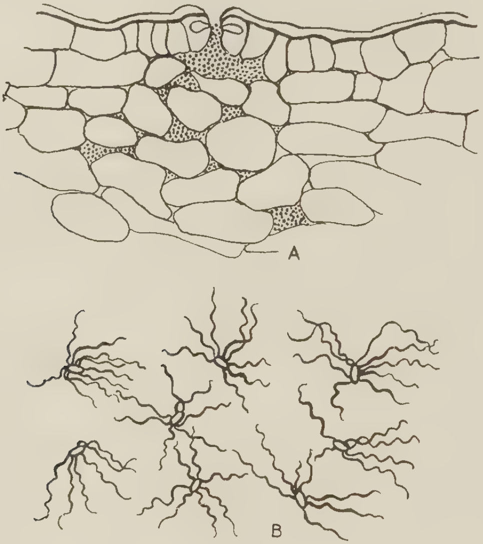

FIG. 164.—A, section through rind of a mandarin orange. At an early stage of infection showing bacteria in substomatal cavity and adjoining intercellular spaces; bacteria merely indicated by dots. B, bacteria with flagella by which they swim about in films of water or make their way into wounds. Magnified about 1300 diameters. (*After Doidge* (1917).)

Leaf infections have only rarely been noted. These start at thorn pricks or small wounds as dark-brown spots surrounded by yellowish zones. The injured tissue finally falls out, leaving a hole. (Doidge 1917).

Causal Agent.—The cause of this disease has been shown to be due to a bacterium, and the salient characters are described by Doidge as follows:

> *Bacillus citrimaculans.*—Causes spot disease of Citrus, attacking fruit and branch, rarely found on leaves; attacks the parenchyma, first occupying the

intercellular spaces, then breaking down the cell walls; in nature, attacks lemons, oranges and naartjes (mandarin), and in addition has been successfully inoculated into limes, shaddock, grapefruit, citron; Seville oranges are resistant.

A slender rod with rounded ends, 1 to 4 by 0.45 to 0.7μ, average 1.5 by 0.5 to 0.6μ; motile by 5-1-peritrichous flagella (Fig. 164); conspicuous capsule but no spores; involution forms in broth containing high percentages of NaCl; stains readily by usual stains and exceptionally well with gentian violet and by Gram's method.

Forms showing subcircular yellow colonies on nutrient agar with dense, grumose center; liquefies gelatine, clouds nutrient broth, forming pellicle and sediment; does not liquefy blood serum; coagulates milk with precipitation of casein and extrusion of whey; the coagulum is not redissolved; no growth in Cohn's solution; characteristic growth in Uschinsky's solution.

No gas in fermentation tubes, acid with dextrose, lævulose, galactose, maltose, saccharose and mannite, but not with lactose, glycerine, dextrin or starch. Nitrates reduced with evolution gas; tolerate up to 10 per cent NaCl; no growth in broth over chloroform, indol produced in media containing peptone.

Aerobic, facultative anaerobe; killed by sixty minutes' exposure to sunlight; T. D. P. 62°C., maximum for growth 43°C.

Contributing Conditions.—In a majority of cases, infection appears to take place through wounds, although Doidge has obtained some indications that the organism may effect an entrance through the stoma. This organism grows well in the presence of orange oil or lemon oil, often filling the oil glands on the rind. It appears to be active in the cooler part of the year (July in South Africa), starting after or during a period of steady rains. It is probable, however, that the most suitable temperature for its activity is considerably higher than that for Citrus blast in California. Doidge (1917) states that the optimum temperature for the growth of the organism in cultures is 95°F. (35°C.), which is almost the upper temperature limit for the Citrus-blast organism. The South African bacterium is reported to grow very slowly at 59 to 64.4°F. (15 to 18°C.), temperatures at which the Citrus-blast organism grows rapidly. In fact, the optimum temperature for development of Citrus-blast lesions is near 60°F. (see p. 449). In most other respects, the contributing conditions appear to be similar in the two diseases.

Control.—No experiments in control have been reported. Doidge suggests that improvement in sanitation of the orchard would be beneficial. Its similarity to Citrus blast and black pit, in dependence on wounds and other factors, would indicate that the same suggestions as those given for blast and black pit might prove of value. Since, however, control measures for even the same identical disease must often be modified to suit different climatic conditions in different localities, the benefit of any of these suggestions in connection with California conditions when applied in South Africa could be known with certainty only as a result of experimental tests.

ANTHRACNOSE STAINS AND SPOTS

Anthracnose is a disease in which fungi, such as *Glœosporium limetticolum*, *G. foliicolum* and *Colletotrichum glœosporioides*, take either a primary or secondary part. A number of different forms of spots, rots or markings on Citrus fruits have gone under the term anthracnose. On young lime fruits, the first-named fungus, *G. limetticolum*, produces severe effects, resulting in pitting, distortion or corky large scabs (p. 461). On other varieties of Citrus fruits, usually in their mature state, some strains of *C. glœosporioides* may produce (1) surface stains often taking the form of "tear stain," (2) dry hard spots and (3) soft rotting (p. 396). The first will be known as anthracnose stain, the second anthracnose spot and the third anthracnose rot. *G. foliicolum* produces an anthracnose spot on tangerine and Satsuma oranges in Japan. The characteristics of the fungi, *C. glœosporioides* and *G. limetticolum*, are given in Chap. XIV under Twig and Leaf Diseases; those of *G. foliicolum* are found here. The last two effects are usually found on rather old, ripe fruit.

ANTHRACNOSE STAIN

This is a stain on the unbroken surface of the rind taking on various shades of color, but usually a reddish or reddish-brown discoloration. Usually this stain only slightly injures the appearance of the fruit, but since it cannot be washed off, it lowers the grade. It usually occurs on the fruit before it is picked and should not be confused with red blotch, which is a storage trouble. This stain is often spoken of as "tear stain" because it frequently covers an area such as a drop of water would in running down over the side of the fruit.

History and Distribution.—Staining known as "tear stain" was first attributed to the anthracnose fungus in Florida by Rolfs (1905). Tear stain probably occurs in every Citrus-producing country. It is very common, as observed by Lee, in the Philippines and Java, is frequently seen in China and Japan and is also known to occur in the islands of the Pacific, such as Guam and Hawaii. An investigation of tear stain in Florida was made by Winston (1921), who concluded after careful experiments that "practically all of the so-called withertip tear stain in Florida was caused by rust mite" (see p. 506). Winston's inoculations with certain cultures of *Colletotrichum glœosporioides* failed to produce "any tear stains or other positive reaction" on Citrus fruits.

In California, several workers have produced stains, which may be known as true anthracnose stains or withertip stains, by inoculation with pure cultures of certain strains of *C. glœosporioides*. In experiments by Fawcett (1913*c*), suspension of spores poured over lemon fruits of various ages produced in two weeks faint reddish stains in blotches and lines where the spores had run down over them. In four weeks, they were quite pronounced and resembled those appearing on lemon fruits in the orchard. The spots developed on green, half-grown fruit and also on mature fruit. Other fruits kept under the same conditions without application of spores remained unstained. It was later learned that C. N. Jensen in 1910 in an unpublished manuscript and C. O. Smith in 1911 had both produced a similar reddish stain by inoculation with spores of *C. glœosporioides*. Later, a dull reddish-green stain was produced by Barrett (1915*b*) on orange fruits. This type of stain was common on both lemons and oranges in California in 1914, the year after the "freeze" of 1913.

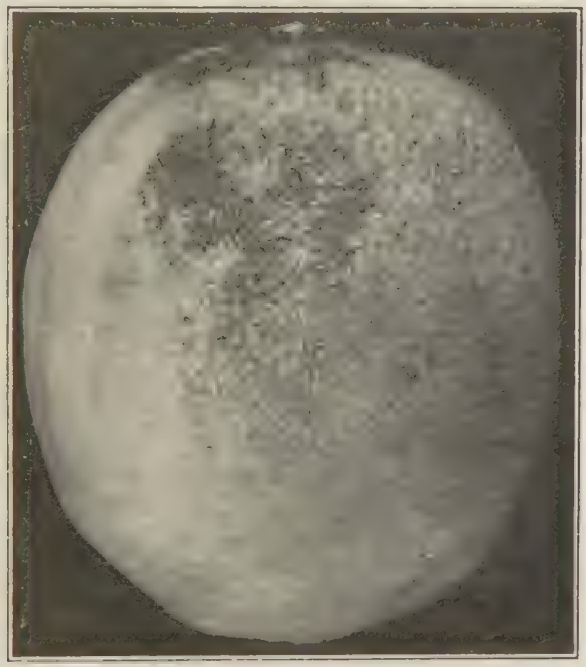

Fig. 165.—Anthracnose tear-stain on California orange. (*Photo by J. T. Barrett.*)

While Winston's experiments show that much of what has formerly been known as tear stain in Florida is due indirectly to rust-mite effects, certain varieties or strains of *C. glœosporioides* are also capable of producing a stain often fainter in color but similar in general appearance. This subject should receive further investigation with various strains of the fungus. It is probable that some strains of the fungus are incapable of causing any effect, while others may readily produce the staining.

Symptoms.—The symptoms of true anthracnose stain, as it occurs in California in the absence of rust mites, are superficial markings on the surface of the apparently unbroken rind. These may occur in streaks or bands or they may occupy a large portion of the surface of the fruit (Fig. 165). In the "tear-stain" form it appears as if formed by a drop of dew or rain water running down over the surface, leaving infection in its track. It should not be confused with the storage effect known as red blotch in California nor with rust-mite tear stain or melanose tear streaking in Florida and elsewhere (pp. 440 and 505). To the unaided eye the surface usually appears unbroken, normal and merely stained. The stain is dull reddish or dull reddish green, depending somewhat on the maturity of the fruit. On very ripe fruit late in the season, it may take on a brownish shade, resembling rust-mite stain. With a hand lens the stain appears to be due to surface cells that have been stained but not visibly broken down. Usually there are numerous appressoria or contact pads of the fungus. In some cases under the microscope, hyphæ may readily be seen, partly embedded in the surface and connected with the contact pads.

Contributing Conditions.—Anthracnose stain is favored by heavy dews and fogs, long periods of rains, the presence of dead twigs or dead parts containing the fungus and probably by the maturity of the fruit and weakness of the rind in case of fruit grown on trees lacking vigor. In California, it has been observed on lemons, especially in the spring or early summer of wet years on tree-ripe fruit. Trees weakened by gummosis or root diseases or showing deterioration appear to have fruit most susceptible to this anthracnose stain.

Control.—When it becomes necessary to prevent anthracnose stain, spraying with strong lime-sulfur solution or Bordeaux mixture would probably prevent its development. The elimination of dead twigs or branches on which the spores develop would also be a means toward prevention. It does not, however, as a rule, become serious enough in dry countries, such as California, to call for application of control measures.

ANTHRACNOSE SPOT

Anthracnose in the form of dry, hard spots in the rind occurs on various varieties of Citrus fruits. They are often known also as withertip spots. Spots of this same general nature may also be formed by a number of other microorganisms besides the anthracnose fungus, for example, Alternaria (p. 464), and presumably at times by physiological breakdown of the rind. For this reason, a number of spots other than those due to the anthracnose fungus have probably been known in the earlier literature under the name of anthracnose. Anthracnose spots, except in the case of lime fruits, occur most often on old or very mature fruits, and the fungus probably depends in most cases on injuries for its entrance.

History and Distribution.—In Florida, Rolfs (1904) showed that by applying spores from pure cultures of the anthracnose fungus to the slightly injured epidermis, brown-colored spots were produced on lemon fruits similar to certain spots occurring in the orchard and storage.

He reported that attempts to infect lemons through the uninjured skin, however, failed uniformly. Rolfs referred to the disease as being especially severe during the winter of 1901–1902 and again in 1910–1911. The anthracnose spot of grapefruit in Florida was described by Hume (1904), who reported having first observed it in 1901. Spots of the same general character have been reported by many workers. On lemons in California, spots attributed to anthracnose were reported by R. E. and E. H. Smith (1911) and Essig (1911). In some recent inoculations with pure cultures in slight injuries on the rind of lemons and oranges, the writer has shown that some varieties or strains of the anthracnose fungus in California readily produce the dry, hard spots under ordinary temperatures of 60 to 70°F., while injuries of the same kind without the fungus do not produce the same kind of spots (Fig. 167A, B).

Spots of nearly the same characteristics may also be produced by inoculation with strains of Alternaria and Fusarium. At rather high temperatures, 80 to 90°F., injuries alone result in shallow brown spots without any known entrance of organisms. A brown spotting of mandarin fruits in New South Wales, Australia, has been ascribed by Darnell-Smith and Mackinnon (1916) to the anthracnose fungus. Anthracnose is reported by Doidge (1924*b*) as common but not serious on oranges and lemons in South Africa. Cold-storage spots, now thought to be a physiological breakdown, have, as mentioned by Hawkins (1921), external appearance similar to that of true anthracnose and may be mistaken for it. It is not to be wondered at that this form of breakdown has apparently been called anthracnose spotting, in the earlier investigations. Such breakdown furnishes one means by which this fungus may gain entrance to the underlying spongy layers of the peel under the proper subsequent conditions of moisture and temperature. The presence of the fungus is, therefore, not a proof that it was responsible for the initiation of the breakdown.

Symptoms.—The anthracnose spots, as produced on mature oranges, in recent inoculation experiments, develop very slowly into hard, depressed, brown spots, usually affecting only the rind but sometimes extending through the rind into the membranes beneath (Fig. 166). On very ripe fruit, it may sometimes develop into the anthracnose rot described on page 396. As described by Rolfs (1911), anthracnose manifests itself by brown or dark-colored, sunken patches occurring on the skin of the fruit. The darkened spots may be regular or irregular in outline. The lesions may occur as a number of small spots or may involve a large portion of the fruit (Rolfs, Fawcett and Floyd 1911).

Some examples of spots originating directly from spores placed in needle pricks may be given. On ripe oranges, spots ⅛ to ⅗ inch (3 to 15 millimeters) in diameter in 1 week, at about 75°F., were slightly sunken and cinnamon brown. Discoloration and breaking down of tissue extended through the rind and into the divisions and pulp. On mature lemons, spots $\frac{4}{5}$ inch (20 millimeters) in diameter in 1 week were warm

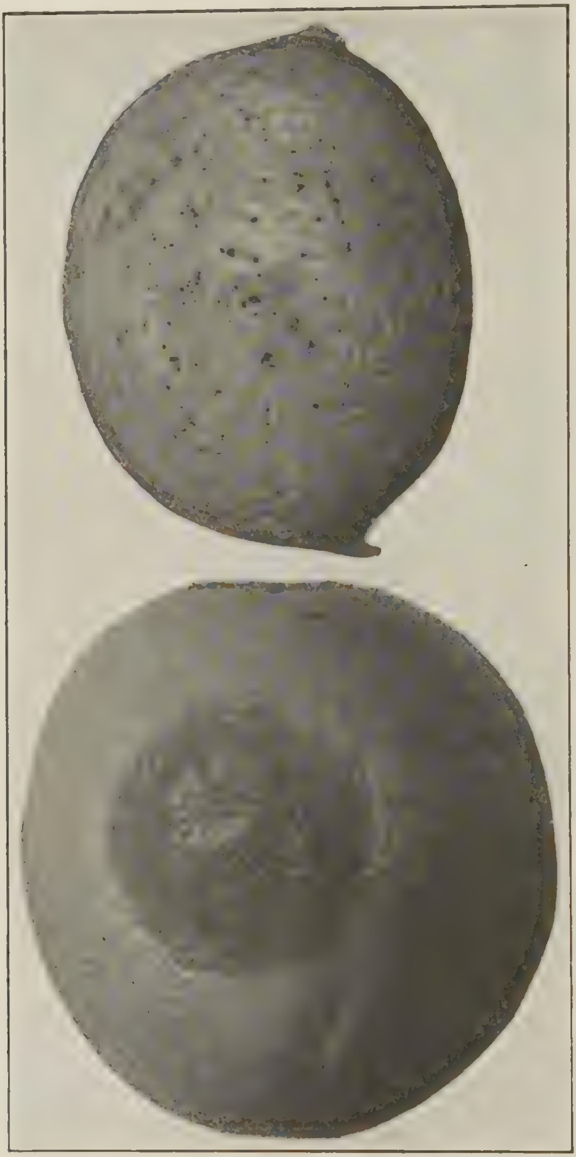

FIG. 166. Anthracnose spots on orange and lemon produced by spores of *Colletotrichum gloeosporioides*. (*Cal. Exp. Sta.*)

sepia or dark snuff brown (warm sepia or bister) on the surface, with a dark discoloration extending $\frac{2}{5}$ inch (10 millimeters) into the pulp. It is unusual, however, for the effect to be so rapid or extended. A more average example is a recorded spot of 4 millimeters in diameter in six days, 8 millimeters in sixteen days and 9 millimeters in twenty-two days, at which time the spot had about reached its maximum. On cutting through the rind, a reddish border was often seen, but not invariably formed between the discolored and sound tissue (Fig. 167A, B).

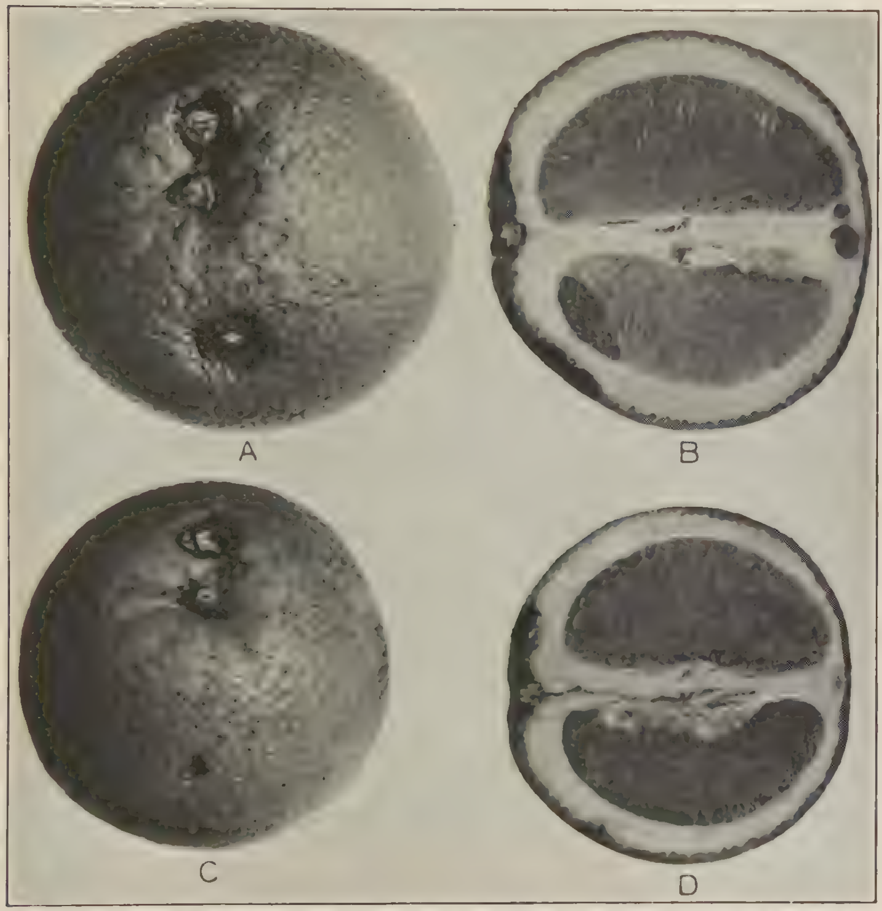

FIG. 167.—A and B, anthracnose spots on oranges produced by puncture inoculations with *Colletotrichum gloeosporioides* spores. C and D, similar spots produced by inoculations with spores of *Alternaria citri*. (California strains.)

In California, on lemon fruits still on the trees, a different spot, affecting only part of the thickness of the rind, has been attributed to the anthracnose fungus, although some doubt exists as to its real origin. It consists of numerous small spots, usually on the exposed side of the lemon fruits, of a reddish color, sunken, hard and extending only part way through the thickness of the rind (Fig. 166). In northern California, a speckling of lemon fruits, consisting of brown or black spots instead of red, is thought to be a form of necrosis (black pit) due to a bacterium (p. 447).

Contributing Conditions.—Anthracnose spot is probably started, in most cases, by slight injuries or weakness of the fruit (Fig. 168). Fruit on poorly nourished trees or trees lowered in their vitality or vigor are, as a rule, more subject to anthracnose spot than fruit on sound healthy trees. When conditions are right for its development, the presence of dead twigs and dead branches on which the spores of the fungus are apt to be abundant may contribute to its occurrence.

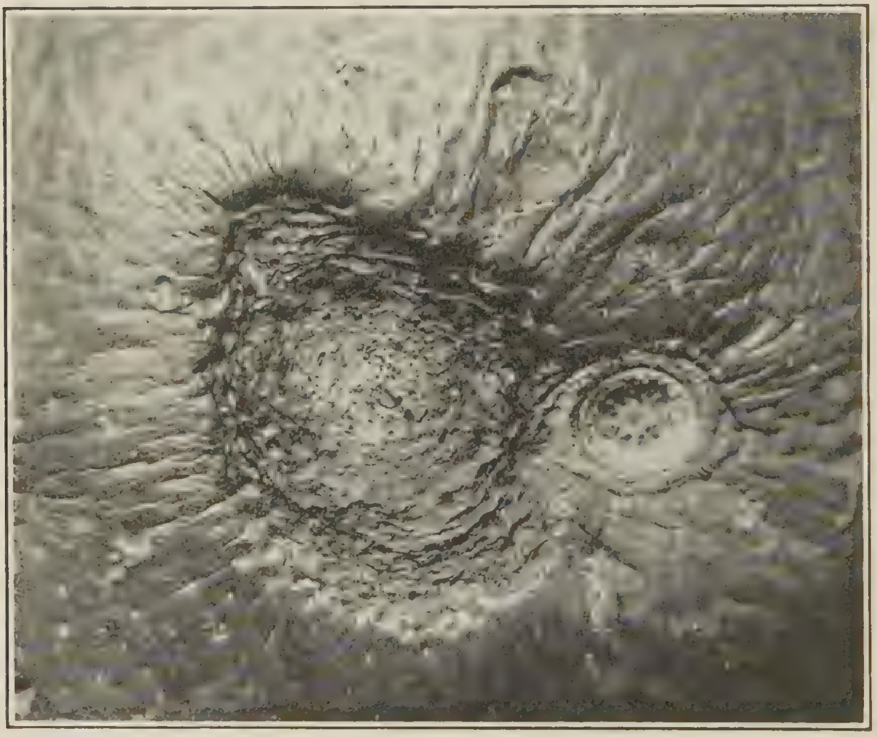

Fig. 168.—Anthracnose spot near stem-end of Washington Navel orange magnified showing the spore-bearing bodies (acervuli) as small black dots. This spot originated in a slight injury from hail. (*After Barrett* (1922).)

Control.—As in the control of certain other diseases, already discussed, which are begun, in large measure, by injuries or by weakness of the tree, the prevention is largely an indirect one. Cultural operations directed to growing strong healthy trees, avoidance of severe shocks or extremes and avoidance of injuries where possible, are important. Sanitary pruning out of all dead branches, as far as this is economically feasible, is also a good practice. There is much difference of opinion among growers and investigators as to the value of spraying for anthracnose either in California or Florida. In California, anthracnose has not appeared to be of sufficient importance to call for systematic spraying. In a climate like that of Florida, the spraying and pruning schedule used against melanose and scab will probably also protect the fruit against most of the danger from anthracnose spot.

ANTHRACNOSE OF THE LIME FRUIT

Anthracnose due to the fungus *Glœosporium limetticolum* Clausen is a very severe disease of lime fruits, especially in southern Florida and in parts of the West Indies. The same fungus attacks the leaves, twigs and blossoms. The history, distribution, causal agent and contributing conditions have been discussed on page 283, but the symptoms on the fruit and suggestions for control will be included here.

Symptoms on the Fruit.—Rounded, shallow spots to deep, depressed cankers occur on lime fruits, often causing them to become misshapen. The fruit is attacked while it is young and rapidly growing. The flower buds, when attacked, turn brown and fall off before opening. If severe infection occurs later as the buds open, the flowers may be shed before the fruit sets. Later attacks on the young expanding fruits, if not so severe as to cause them to drop off, usually result in corky spots and frequently in distortion of the fruit as it grows. After the fruit is three-fourths its normal size, it becomes immune to further attack. As the fruit grows, the previously affected tissue tends to be cut off from the remainder of the fruit. Sometimes, a cleavage between the sound and healthy tissue forms, and the scabs tend to be sloughed off, leaving shallow or deep scars, depending on the severity of attack (Fig. 169). This corky, scab-like effect on lime fruits should not be confused with verrucosis or scab due to a different fungus.

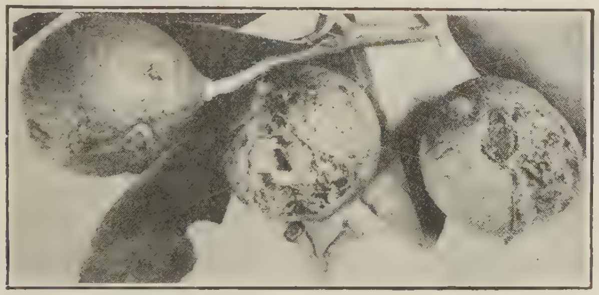

FIG. 169.—Effect of anthracnose of limes on young fruits. (*After Cook and Horne* (1908).)

Control.—The control of anthracnose of the lime may be effected only by protecting the new growth and developing fruit by either Bordeaux mixtures or lime sulfur. Certain difficulties arise because the flushes of new leaves and twigs and the blossoming of the lime may be somewhat scattered. As Nowell (1923) points out, however, there are "fairly well-marked times of maximum production" which are somewhat constant for a particular locality, and if spraying is done at these times it may be possible to save a large proportion of the fruit. In experiments by Fulton referred to by Nowell, it has been shown that a spray schedule, carefully carried out at time of blooming and early setting, may control the disease.

> The first fruit spray should be made as soon as enough petals have dropped to allow for coating a reasonable setting of fruit. This would be when the bloom is perhaps one-half to one-third advanced. Later sprays will depend upon the progress of the bloom and on weather conditions. In a general way, two or three later applications at intervals of one to two weeks are necessary.

For the first spraying, use Bordeaux-oil emulsion (3-3-50 plus 1 per cent of oil) and for later spraying commercial lime sulfur 1 to 30 to 1 to 40. Certain drawbacks as mentioned by Fulton (1925) also arise, such as the irregular and close spacing of lime trees in a number of cases and the "rough topography of the land and the relatively low value of the crop per tree." Fulton further points out that complete control lies in the direction of ultimately substituting other types of lime. His investigation has shown that many immune varieties are available. These may also serve as a possible basis for attaining immunity by hybridization with the present West Indian lime.

Anthracnose of Satsuma Oranges

In addition to the withertip or anthracnose of limes and the withertip of sweet oranges and grapefruits which are caused by closely related fungi, there is a similar disease of Satsuma oranges, *Citrus nobilis* var. *unshiu*, in Japan which is caused by a fungus, *Glœosporium foliicolum*. This disease is not definitely recorded outside of Japan, although there is a disease of similar character on mandarin orange fruits in Australia which might be suspected as identical to the Japanese Satsuma disease (Darnell-Smith 1916).

Symptoms.—A small area of the skin of the fruit becomes a brown color; the spot spreads quickly, the center of the spot becoming lighter and grayish in color, while the advancing edges remain dark brown or even dead black. The spot is slightly depressed and a very definite line of demarcation exists between the diseased spot and the normal skin. The size and the shape of the spots vary; a spot may be as small as 1/12 to 1/8 inch (2 to 3 millimeters) in extent in its longest dimension, while the largest spot observed was 2 inches (50 millimeters) in its longest dimension. The longest diameter is typically in a lateral direction, as shown in Fig. 171A, B. As the disease advances, small black pustules can be seen forming in large numbers in the grayish center of the lesion; these are the acervuli of the causal fungus and contain the spores in large numbers. The spots appear typically near the blossom end of the fruit, usually just to one side of the navel, never at the navel. The spots have never been observed to occur near the stem end of the fruit.

The injury to the fruits is at first confined largely to the skin and does not extend into the flesh. In the early stages of the disease, therefore, although the skin may be blackened, giving to the fruit the appearance of being badly rotted, it will be intact within and perfectly edible. With the advance of the disease, other fungi intrude, which spread into the flesh of the fruit more readily, and the fruit becomes spoiled for use and promptly rots. The fruits, moreover, when once affected, quickly drop to the ground, where rotting proceeds more rapidly. As a general rule, fruits affected with this disease are a total loss to the grower.

Nishida (1914), who first described the causal fungus, found it very commonly on the young, actively growing leaves of Satsuma trees during May and June, causing a leaf drop. The fallen leaves show watery, cloudy spots on which there appear bright-red pustules which are the acervuli of a fungus. Young, newly formed twigs are also attacked, becoming first a yellowish-brown color and then dead black.

The Causal Agent.—The causal fungus in this anthracnose was described by Nishida as a new species, *Glœosporium foliicolum.*

Hemmi (1921) isolated the fungus in pure culture and by inoculation methods reproduced the disease experimentally on the leaves of a young Satsuma orange tree, thus proving that *G. foliicolum* was the cause of the disease. Hemmi found that leaves of the early Satsuma orange trees were susceptible but that the sweet orange by the same methods did not show the disease nor did pummelo trees nor sour-orange trees. Lee (1923*a*) showed that *G. foliicolum* from pure cultures would cause the rot of the early Satsuma oranges but would not affect fruit of the sweet oranges or pummelos. These results with those obtained by Hemmi point rather clearly to differences between the *G. foliicolum* of Nishida and *G. limetticolum*, of withertip of limes, and *Colletotrichum glœosporioides*, causing withertip of oranges and grapefruits.

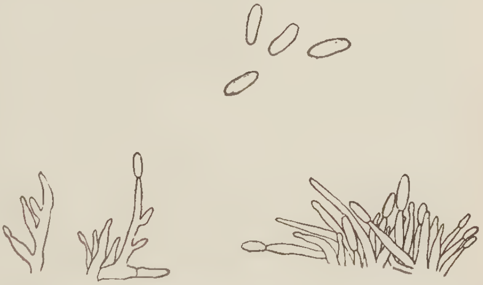

Fig. 170. Showing the spores and conidiophores of *Gloeosporium foliicolum* the cause of anthracnose of Satsuma oranges. Magnified about 300 diameters.

The fruiting bodies of the fungus occurring both naturally on diseased fruits and in culture are the typical Glœosporium acervuli. The masses of spores resulting on the fruits are most often black *en masse*, but in fresh cultures are usually pink. The individual conidiophores are often branching, as shown in Fig. 170, and are characteristically tapering at the tip. The spores when newly formed are elongate and slightly tapering to the ends, and the ends are usually rounded. In old cultures, the spores may assume a number of eccentric shapes. When newly formed, the spores are hyaline, and few or no granular bodies are to be seen. Spores from old cultures, however, become something of an olive shade and are very granular; one or two vacuoles are frequently to be seen in old spores. The size of the spores is from 4.3 to 6.0 by 15.0 to 21.5μ.

Contributing Conditions.—There is nothing known concerning the temperature or humidity relations of the causal fungus except from inferences drawn from the occurrence of the disease. Nishida states that the disease is most common in the spring months when there is an abundance of new foliage. Lee (1923*a*) showed experimentally that, whereas the fruits of only the early maturing Satsuma varieties are affected under field conditions, even the late maturing varieties can be artificially inoculated if the temperatures are maintained to the same degree as the orchard temperature when the early varieties come to maturity. Similarly, mandarin oranges were readily inoculated when the temperatures were raised to those of summer conditions. Apparently, therefore, this anthracnose of Satsuma oranges is a warm-weather disease.

It was also shown experimentally that young immature fruits are not readily infected with the fungus, but that infection takes place much more readily as the fruits approach maturity.

Prevention.—This anthracnose of Satsuma oranges and, as inoculations showed, mandarin oranges has not been reported with certainty outside of Japan, although there appears to be a similar disease in Australia. Since it is apparently not yet established in other Citrus-growing countries, entire exclusion is suggested as the cheapest preventive for such countries. In Japan, where the disease occurs, pruning out of the affected twigs, which serve as sources for future infection, and spraying with preventive fungicides should be effective, since such methods are successful for withertip of limes and lemons.

ALTERNARIA SPOT

A firm, sunken spot on the side of the fruit, usually on the half of which the stem end is a center, is found on oranges late in the season in California. Often associated with this spot is an Alternaria fungus. Inoculation experiments have shown that such spots can be produced by inserting the fungus in punctures. It is thought that the spots always start in some injury or breaking down of the tissue (Fig. 167C, D).

The breaking down of tissue seldom extends deeper than the thickness of the peel. As the spots develop, they change from a light brown to a dark brown and almost black. There is usually not so much tendency for these spots to spread sidewise and enlarge as in anthracnose. The spots increase in size only to a certain limit, a maximum of about 10 to 15 millimeters in diameter, and then come to a permanent standstill.

In cutting through, there is often seen, as in case of the anthracnose spots, a margin of reddish stained tissue. According to Ridgway's chart, the surface colors vary from chocolate brown to Prout's brown to cinnamon brown. The narrow red margin may be English red in color. Sometimes on very mature fruit the fungus may advance from these spots along the membranes of the pulp, reaching the center of the fruit, in which the characteristic Alternaria rot, elsewhere discussed, may develop.

The contributing conditions and control are thought to be the same as for anthracnose spot due to *Colletotrichum gloeosporioides*. The Alternaria and Colletotrichum spots are not easily separated without cultural tests. Frequently both fungi are present in the same spot.

CYTOSPORINA SPOT AND ROT OF MANDARIN ORANGES

Spots appearing on the rind of mandarin oranges in the markets at Rome are described by Campanile (1922). This disease, due to the fungus *Cytosporina citriperda* is reported to have destroyed a large amount of this variety during 1922. No control measures have been reported.

Symptoms.—At first, a rounded, generally slightly depressed spot appears from about $\frac{1}{3}$ to $\frac{3}{5}$ inch (8 to 15 millimeters) in diameter, reddish brown at first, turning black later. It affects the rind and also causes the divisions or carpellary walls to become firmly attached to the inner peel so that they tear away with it, leaving bare the underlying pulp. Under older spots, the rind, with these attached walls, is reduced to a black pulpy mass which extends to the flesh of the fruit. In eight or ten days, secondary spots occur at other places on the rind, gradually assuming the same characters as the primary. Underlying flesh of the fruit is black, granular and thicker in consistency than the normal.

In some cases, the center of the fruit is also reached, and rarely are the seeds covered with a black, granular, hard layer of fungus material. The primary spots start from outside, probably at an injury, while secondary spots may arise from an internal fungus mycelium which has spread inward and laterally from the primary spot.

Causal Agent.—Artificial inoculation by Campanile (1922) has shown that a fungus, *Cytosporina citriperda*, is capable of producing this mandarin fruit spot. The fungus usually produces its fruiting stage within the fruit, only rarely on the surface. At an advanced stage of the disease, the inner side of the rind becomes dark yellow. A black, irregular, lamelliform stroma, sometimes involving the membranes between two contiguous segments, appears and becomes densely covered with pycnidia on both sides. It was at first considered probable that an injury or wound is necessary for the entrance of the fungus and the initiation of the spots, but later inoculation experiments showed that spots occurred after fifteen days by placing stroma with pycnidia on the uninjured rind.

The fungus grows rapidly on orange-juice agar, developing pycnidia in forty-eight hours, the spores filling the pycnidium before the walls are fully formed. The hyphæ are olive colored, generally swollen in the vicinity of the septa and anastomose frequently. The colonies on petri-dish cultures are surrounded by gray-green halos of aerial hyphæ possessing thin, whip-like hyaline tips. After the pycnidia are formed, cordons of hyphæ are formed, increasing in thickness and giving the stroma an almost cartilaginous consistency. In addition to the pycnia spores, slightly fuscous conidia are also sometimes formed in the aerial hyphæ (Campanile 1922).

OLEOCELLOSIS

(Citrus-oil Spot, Green Spot)

This is a spotting of Citrus fruits due to the action of oil liberated from the oil glands of the rind. This has suggested the term oleocellosis. In one form, it is called "green spot," but it is not always green in color. It is most common on fruit picked in cool, damp weather of the fall and winter, but it may also occur on fruit still on the tree. Green spot, the most conspicuous form, develops on fruit picked while still green in color. As the fruit colors in curing, certain areas, where oil from the glands has come in contact with the surface, remain green and slightly depressed between the oil glands. On fruits already colored, the liberated oil may cause similar effects on the rind without the spot being green.

History.—For a number of years preceding 1914, the lemon growers in California were troubled at times with this green spot, and its cause had remained a mystery. Many theories had been advanced to explain its occurrence. Some experiments by J. D. Culbertson of the Limoneira Company, Santa Paula, Cal., led to the discovery of the cause. He first produced what appeared to be typical green spotting on lemons by pressing and rolling them against boards. After storing these fruits for some weeks, typical green spots developed. At that time, the spotting was thought to be due to the injury to the cells themselves rather than to the oil. It was also noticed at that time that fruit picked from branches that had been cut off in pruning and had lain on the ground developed more green spotting than others picked directly from the trees. Other lemon growers had noticed that fruit picked when dark green and wet usually developed more green spot than similar fruit picked dry from the same trees. Culbertson states that in washing a lot of lemons picked late in November, 1914, while still wet from an early morning shower, a strong smell of lemon oil was detected at the washer and that inspection of these lemons after storage showed them to be severely injured from green spotting. This led him to suspect that lemon oil itself might be responsible for the trouble, and early in December, just after a shower, some lemons hanging on the tree were injured so that the oil ran out over the uninjured surface. Some of this oil was also placed on the uninjured surface of other fruit. The sinking of the tissue as in the green spot took

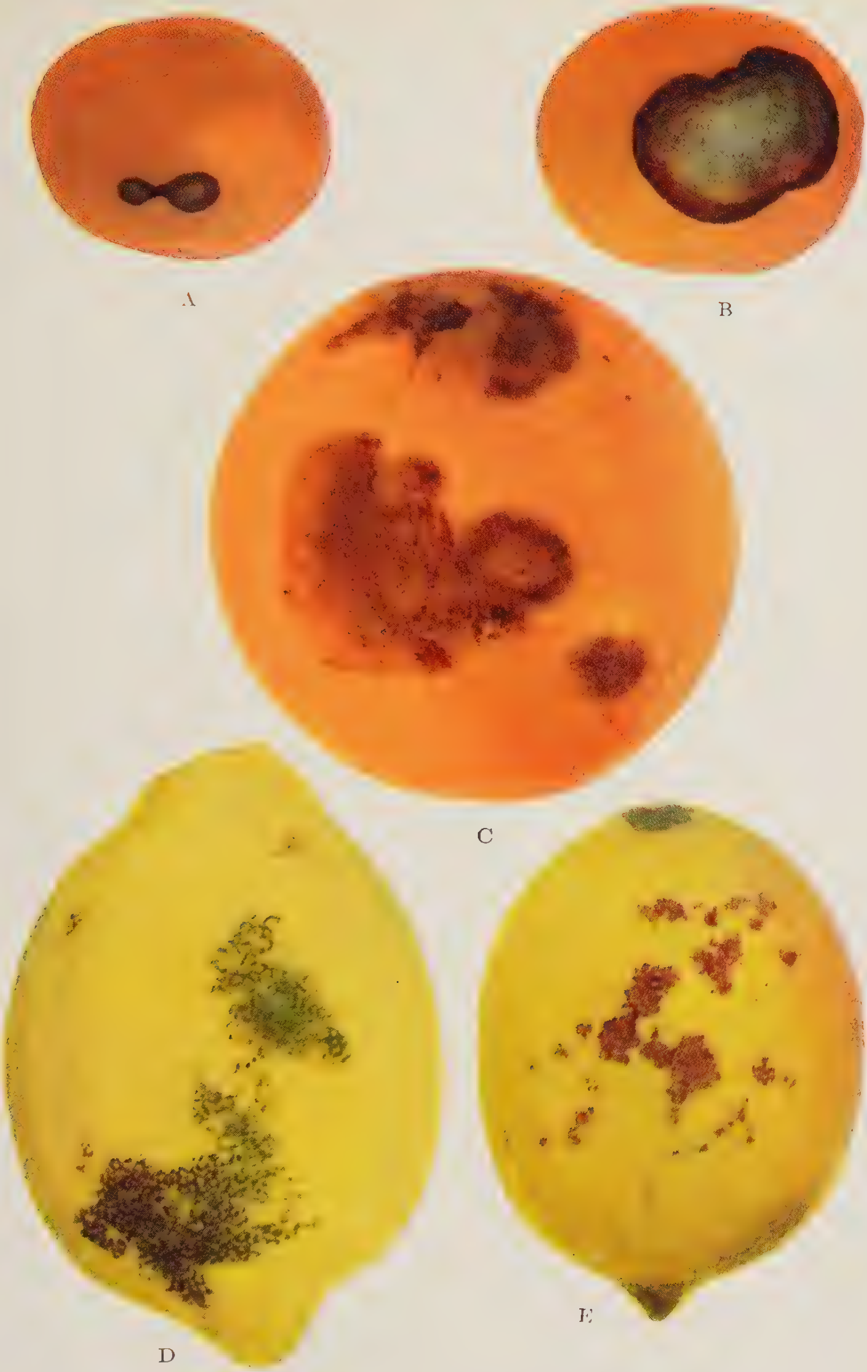

Fig. 171.—Anthracnose spot, brown spot and oleocellosis or oil spot. A and B, Anthracnose on tangerine and Satsuma oranges in Japan, due to the fungus *Gleosporium foliicolum*. C, Brown spot of the navel orange, cause unknown, developing in storage at about 60°F. on wrapped oranges. D, Green-spot stage of oleocellosis, which developed in storage, due to oil previously liberated from the rind. E, Brown-colored oleocellosis spots, which developed on the tree, induced by hail which had liberated oil from the rind.

place, but the green color did not appear as it had on the stored fruit. It was later found in Fawcett's (1916*a*) experiments that the green color rarely remains on spots injured by lemon oil if the fruit is left on the tree, but that if it is picked and stored the green color usually remains fixed.

In 1915, Fawcett (1916*a*) carried out a large number of experiments with lemon and orange fruits, leaves and shoots of various ages, both on and off the tree, and in moist and dry atmospheres, with the result that this type of spot was shown to be caused by very minute quantities of Citrus oil acting on the tissue for very short periods of time. These results were afterwards confirmed by Thomson (1922) in oranges under South African conditions and by Burger (1923*a*) with oranges picked green under Florida conditions.

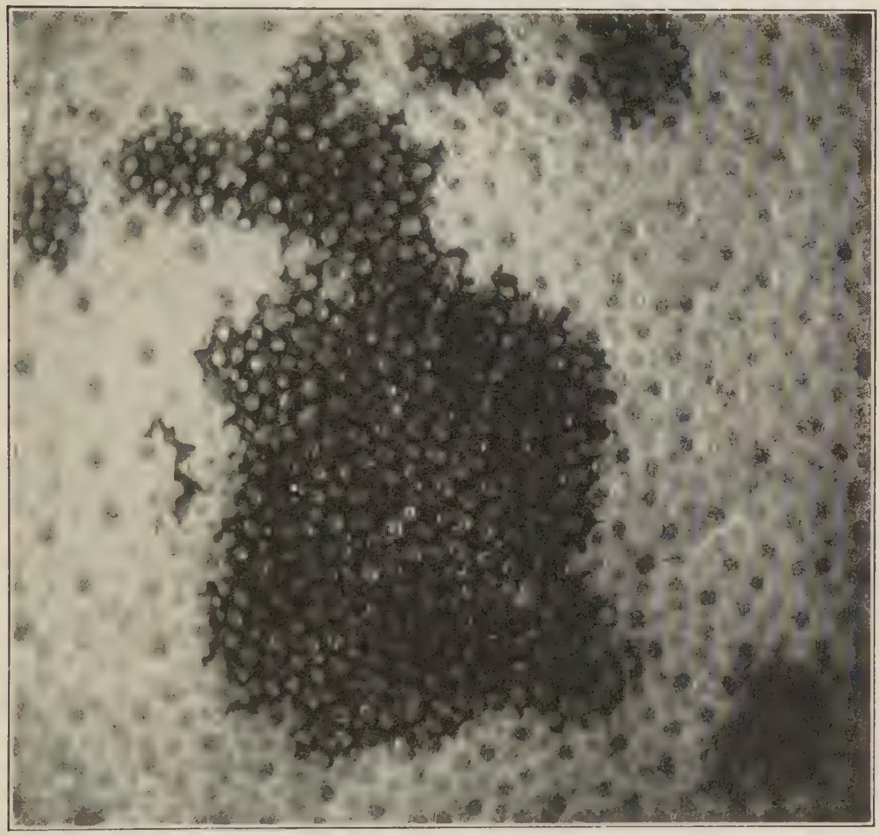

FIG. 172.—Oleocellosis or green spot on lemon rind due to the action of oil liberated from some of the oil vesicles. Magnified about 3 times. (*Photo contributed by J. T. Barrett.*)

Symptoms.—Oleocellosis or oil spot is characterized by a slight sinking of the tissue between the oil glands in the rind, leaving them standing out prominently over the surface of the affected areas. These spots vary greatly in size and shape. They are usually circular in outline and ordinarily do not exceed ½ inch in diameter (Fig. 171D, E). They may, however, be irregular in outline and at times involve the greater portion of the surface of a fruit. The oil liberated from the rind by any cause appears to act powerfully and quickly upon all the cells at the surface with which it comes in contact, except those immediately surrounding the oil glands. This leaves the oil glands standing out prominently over the surface of the area occupied by the spot (Fig. 172).

The lemons which come to standard size while green appear normal when picked but, on being set aside to cure, develop spots which remain green, while the remainder of the rind colors normally (Fig. 171). Such fruits may be kept for weeks without enlargement of the spots and without change in their green color. Sometimes the green is replaced after a long time by a reddish or brownish color, but the normal color does not develop in the spots. This lowers the grade of the fruit, but usually does not injure seriously its keeping quality. Lemons that have already colored before they are picked may in some cases show spots of the same kind, though not green and, therefore, less conspicuous. Oranges picked too early or when they are immature may also be severely affected by the green spot (Fig. 173).

Experiments with Lemon and Orange Oil.—Many different experiments were carried out, the most interesting one of which is here given, followed by a summary of the results of all:

Nineteen full-sized, light-green lemons were placed in a row on the table in the laboratory, and drops containing 0.01 cubic centimeter of lemon oil were placed on each. The drop on the first was rubbed off immediately with a piece of cotton. The other drops were rubbed off after they had remained on the rind different periods, namely, 3, 6, 7, 8, 9, 10, 15, 20, 30 and 45 seconds; 1, 2, 5, 10, 20 and 30 minutes; 1 and 2 hours, respectively. A visible effect of the oil was seen in a very short time on those left on 2 or more minutes; in 24 hours it was apparent on all fruit on which the oil had acted for 8 seconds or more. On the lemon on which the oil had acted 2 minutes, a slight effect was visible in 20 minutes after the oil was rubbed off, and on the lemon on which the oil had acted 5 minutes, the effect was visible in 10 minutes after the oil was rubbed off. On all those on which the oil had acted less than 8 seconds, no effect was visible, even after several weeks. The severity of effect was in proportion to the length of time the oil had acted upon the rind with slight variations, probably due to differences in the fruit. The experiment showed clearly that the action of the oil in breaking down the surface cells is extremely rapid.

Summary of Experiments

1. The effect of a given amount of oil from the rind was greater on fruit in a moist atmosphere than on similar fruit in a dry atmosphere.
2. The moisture being the same, the effect was greater on green or immature fruit than on fully colored or mature fruit.
3. The effect was greater on fruit just picked than on similar fruit picked for some days.

4. The action of small amounts of oil, for example, such as could be liberated by a hard pressure of the thumb against the rind of a dark-green, freshly picked, moist lemon (or by 0.01 cubic centimeter of the commercially expressed lemon oil), was sufficient to cause the typical green spotting. The green color appeared to be fixed in the portion acted on by the oil, while the remainder of the rind colored normally in the usual process of curing in four to six weeks.

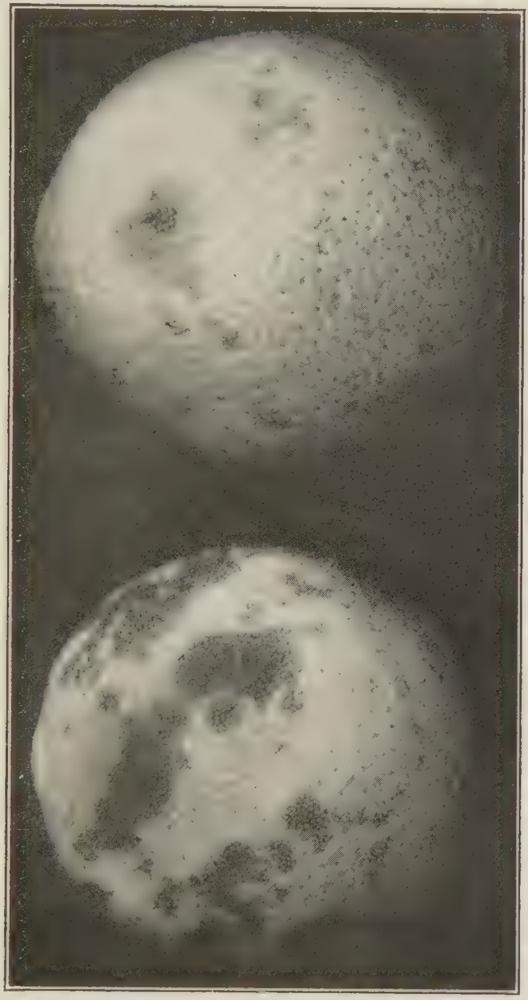

FIG. 173.—Oranges showing spots due to oil liberated from the rind. (*Photo by J. T. Barrett.*)

5. The action of a large amount of lemon oil, such as 0.1 cubic centimeter or more, under the same conditions, caused the spots to become brownish or reddish rather than green. When the amount was sufficiently increased, the breaking down of the tissue was so great that blue mold started in a few days.

6. When the fruits acted on by the oil were left attached to the tree, only in rare cases did the green color remain. As the fruits continued to grow and mature, the sunken areas were partially restored and only slight scars were left.

7. Under similar conditions, the oil from the rind of oranges acted upon other uninjured oranges in the same manner as the oil from the rind of lemons acted upon other lemons.

8. The oil caused the spotting of tender leaves and shoots and the withering of flower buds when squeezed out upon them.

9. The action of the oil on the surface of the rind is extremely rapid, as shown by the fact that 0.01 cubic centimeter of lemon oil acting for 8 seconds was sufficient to show afterward a visible effect on the rind.

Contributing Conditions.—Green spotting has been observed almost exclusively on fruit picked during the late fall, winter and early spring. This period in California, in general, corresponds to the season of moist atmospheric conditions due to frequent rains and fogs. It has also been observed, as stated before, that fruit picked while wet after a rain is more apt to spot than that picked dry. The experiments have shown that the same quantities of oil, other things being equal, have more effect in a moist than in a dry atmosphere and on wet than on dry fruit. The lemons picked at the above-mentioned season are apt to contain a higher percentage of dark-green fruit than at other seasons. The work of Chace and his associates (1921) has shown that the amount of oil tends to be greater in the late fall than at other seasons.

Experiments have also shown that the oil had more effect on green than on ripe fruit. The explanation would, therefore, appear to be this—that in the process of picking and handling, certain small amounts of oil are liberated on the surface of the rind, and that this oil is able to cause severe spotting in a moist atmosphere or when the fruit is wet, as is often the case during the rainy season, especially when it is green. That no serious trouble from green spotting is experienced in summer is probably due to the drier atmosphere and the greater maturity of the fruit. Furthermore, in a dry atmosphere, the oil quickly volatilizes and, therefore, has little time to act.

The size of spots on fruit on the trees produced by scratches or bruises from passing teams appears to be out of all proportion to the mechanical injury inflicted. In many cases, an area may be traced where the oil has spread out from the broken cells, and has affected the adjacent tissue in the same manner as has the spotting under consideration. It also seems probable that in like manner the injury caused by red spiders and other mites and insects is increased by the liberation of oil. The injuries caused by the fruit whipping against the branches in severe storms are also probably more severe for the same reason.

Packing-house men have also observed that the spotting of fruit from various groves, even when it is handled under the same conditions, differs greatly. This may be due in part to variations in maturity or growth conditions of the fruit that might modify the structure of the rind and possibly the amount of oil it contains. The oil is probably liberated much more easily from fruits from certain groves than from others, due possibly to differences in the fruit itself. Spots of this same general nature occur as one effect of frost on the surface of the rind (Webber *et al.* 1919). Hawkins (1925) has observed, in the process of artificial freezing of lemons on the tree, that oil is liberated, resulting in spots of this kind.

It is reported by Doidge that a species of Phoma is frequently found in South Africa, apparently invading spots caused by the liberation of oil from the rind.

Control.—The prevention of oleocellosis or Citrus-oil spot lies in avoiding those conditions which contribute to the escape of oil from the glands, especially at a time when the fruit is damp or when green and turgid.

1. Fruit should not be picked when wet either with rain or dew. The necessity of this precaution, especially with lemons, has been proved by numerous examples. Lemons picked in the early morning, after being wet with rain, were badly affected later with oil spot, while those picked from the same trees near the middle of the same day, when dry, had only an occasional oil spot.

2. Fruit picked at the season of the year or stage of maturity most susceptible to oleocellosis should receive extreme care in handling to avoid injuries or knocks that would tend to liberate oil in the rind. It has been recognized for a long time that great care in handling the fruit is necessary in avoiding decay from blue mold (p. 360). To avoid green spotting on susceptible fruit during the critical season, even greater care will doubtless be necessary. Pressing together of the fruit in the picking sacks, letting them drop too far into the field boxes, jolting in wagons without springs on rough roads, rough knocks and jamming in washing, grading and packing are all means that would tend to liberate the oil from the rind.

3. When hot water is used, avoid washing too soon after picking. Fruits picked during cool, damp, periods, especially fruit that is quite turgid as it comes from the orchard, may spot badly if put at once into the washer of hot water. It should be allowed to remain one to three days, depending on the weather, before it is run through the bath of 115 to 120°F.; after such a period, oil is much less liable to be liberated from the rind in washing. With green fruit, if much odor of Citrus oil is detected at the washer, it is an indication that oil spotting may result. In such cases, a greater time will need to be allowed between picking and washing, or the temperature of the water will need to be lowered.

BROWN SPOT OF THE NAVEL ORANGE

A brown spotting confined almost entirely to the navel oranges grown in the upper San Gabriel and Santa Ana valleys in California is sometimes severe in packed fruit during certain years. This type of spot usually becomes noticeable fifteen to twenty-five days after picking, no symptoms being visible while the fruit is on the trees. Brown spot was described

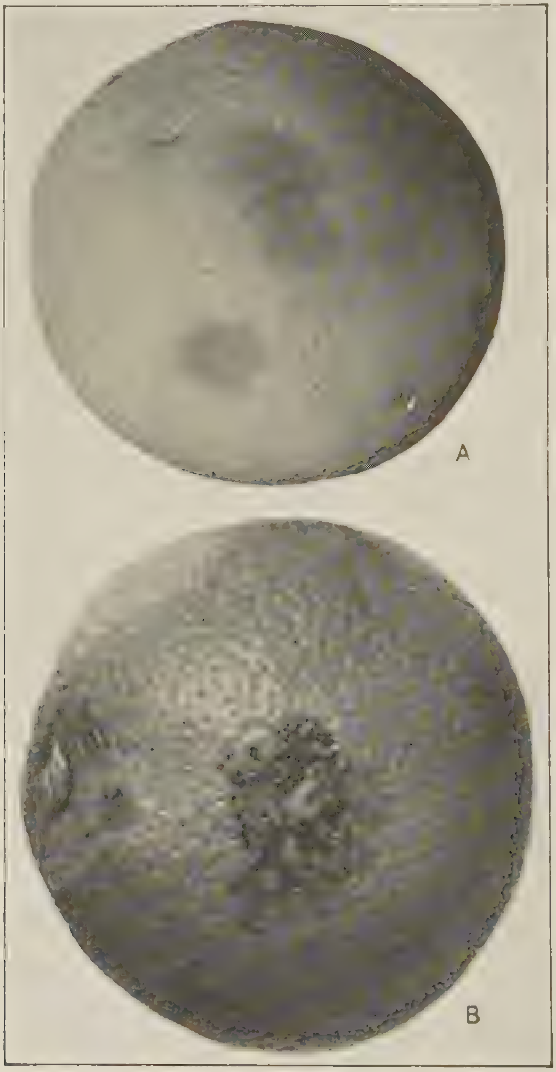

Fig. 174.—A, brown spot of the Navel orange; B, brown-colored spots, probably a type of "brown spots," developing on wrapped Navel oranges after 6 weeks in storage at about 60 to 65°F., California.

and studied by Coit (1910), scientific attention being first called to it in 1909.

Symptoms.—One to fifty brown spots may occur on the surface of a single navel orange and may vary in size from a mere point to 1 inch in diameter. The spots are commonly circular in outline, but may be quite irregular. They may be light brown to almost black in color and are slightly sunken by a collapse of the surface cells (Figs. 171C and 174). The effect may extend inward, usually to a maximum of about one-fourth the thickness of the rind. In this type of spot, no abrasion or opening in the epidermis can be detected with a hand lens. There are similar spots, however, that appear to originate at slight injuries or abrasions (p. 476). Coit's (1910) investigation showed that this brown spot which he studied was most severe on the smoothest, thinnest-skinned navel oranges.

Contributing Conditions and Cause.—The cause of this type of spot is thought to be connected in some way with a physiological or chemical breakdown, the details of which are not understood. Coit (1910) has concluded that the direct cause of brown spot is the oxidation of the protoplasm by enzymes which occur in the protoplasm itself but which are prevented from acting as long as the orange is joined to the tree and receiving water and certain nutritive substances. Thus the resistance of the protoplasm to enzyme encroachments gradually grows less from the time the orange is picked. According to R. E. and E. H. Smith (1911), oranges freshly picked in a season for brown spot show, by the iodine test, an accumulation of starch in scattered areas corresponding to about the size and distribution of brown spots which would have developed if the fruit had been stored for one or two weeks. An accumulation of starch is also shown in spots after they have developed.

Although the cause is not understood, some of the contributing conditions involved may be mentioned. The spots tend to be more severe on fruit picked early than on those picked later in the season. Fruit left on the tree until quite late is as likely not to show this spot at all. In this respect, brown spot differs from similar spots due to injury, which spots are apt to be worse later in the season. Brown spot is also apt to be worse in the upper interior valleys than near the coast. It is worse on the choicest fruit with smooth, thin-skinned rind. The investigation of Coit seems to show that this brown spot was not necessarily connected with frost injury, fumigation for scale insects nor mechanical injuries to the rind.

Control.—There is little to suggest in the way of control. In seasons when this spotting is very bad, holding the fruit on the trees till late in the season, where this can be profitably done, might prove a partial preventive. Nothing definite is known as to means of preventing the development of this type of spotting in packed fruit on the way to market.

STORAGE SPOT OR "POX"

Shallow sunken spots of unknown cause are frequently met with in fruit kept in storage, more especially in cold storage, where air ventilation is poor. These are often referred to as "pox."

Symptoms.—Cold-storage spots are light-colored to brown sunken spots on the rind, varying in size and shape with the variety, thickness of the rind, etc. As described by Hawkins (1921), the pitting begins on grapefruit as small indentations of the skin on any part of the surface. These sunken areas increase in size and may become 0.4 inch (10 millimeters) in diameter and usually about 0.04 inch (1 millimeter) in depth. Irregular-shaped patches may be formed from the coalescing of individual spots. They gradually turn brown, especially on exposure to warmer temperatures (Fig. 175). They are formed by the breaking down of only the layer of tissue containing the oil vesicles. In this respect, they differ from typical anthracnose spots in which more of the underlying tissue is invaded and broken down. It is probable that, with certain strains of anthracnose or other fungi, this physiological breakdown serves to open up the way for the later invasion into deeper tissues, when the fruit comes out of cold storage. The underlying spongy tissue does, however, even without invasion of organisms, appear to become discolored after a long period.

A similar type of spot has been noted on grapefruit picked in November and kept in ordinary storage in packing-house basements till March. Spots are ⅙ to ⅓ inch (4 to 8 millimeters) in diameter, slightly sunken, at first not discolored, but later light brown. The oil vesicles are found to be empty, but no effect is seen in tissues below the tissue containing these vesicles. Some older spots are surrounded by a brown outlying ring ⅗ to ⅘ inch (15 to 20 millimeters) in diameter (Fig. 176). Frequently, the spots join together and cover one-fourth to one-half the surface of a fruit.

Another similar type of spots, irregular in outline and of various sizes, occurred on navel oranges stored by Parker at about 60°F. for about four weeks (Fig. 174B). They were superficial, slightly sunken and light drab in color. Later, the spots gradually darkened to a light brown and then darker brown. The centers of some spots were dark brown with a lighter margin. These spots affected at first only a few superficial layers of cells. Later, by drying, the spots sank deeper and affected other layers. One type of spreading spot occurred in which there was a more indefinite margin, sometimes lobed and with small points of unaffected rind surrounded by sunken portions. The tissue over and around oil cells was affected as well as that between the cells. In this respect, they differed from oleocellosis due to liberation of oil on the surface. Some spots of this type probably originated with slight

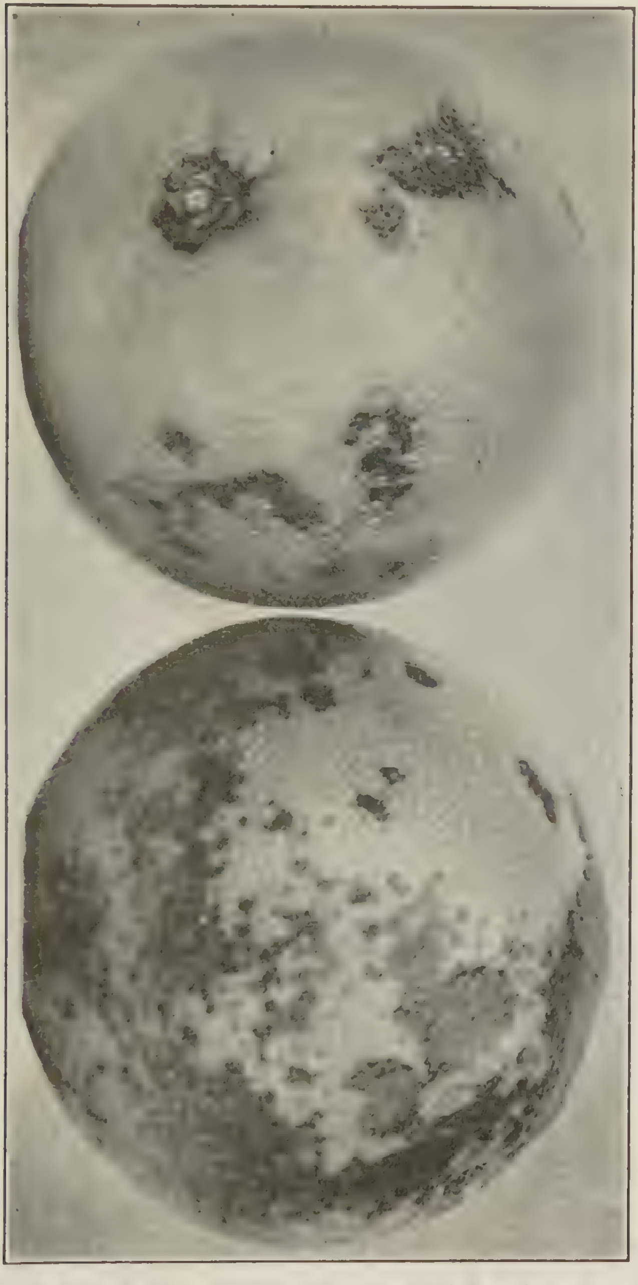

FIG. 175.—Cold storage spots on California oranges held 5 weeks at a temperature a few degrees above 32°F.

injuries to the skin, imperceptible at the time of storage but later becoming points from which breaking down of tissue spread and from which oxidation took place. There is also a possibility that certain common organisms may enter and spread the breaking-down process. Some spots clearly begin at a wound as a center. In laboratory experiments with oranges at different temperatures, it was found that spots of this kind could be started by pricks in the skin with a sterile needle, followed by storage in temperatures of 80°F. or higher. Spots most readily begin near the stem end of the fruit. Further investigation is needed to determine the cause of these spots.

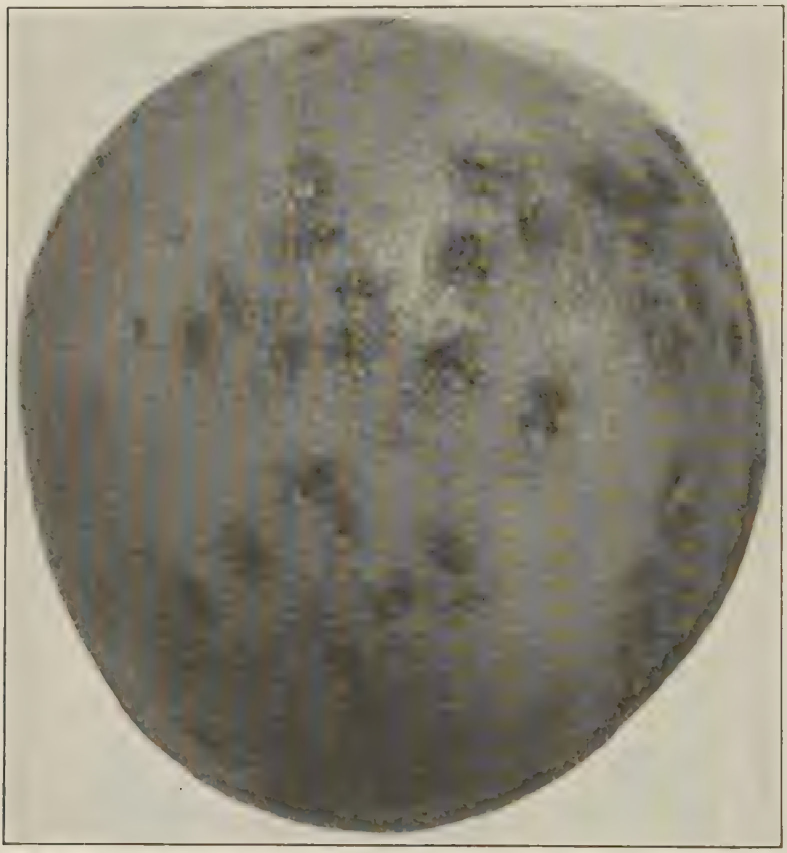

FIG. 176.—Shallow, sunken spots on grapefruit picked in November and kept in common basement storage in California for about 3 months.

Control.—The contributing conditions for cold-storage spots, so far as they are known, are discussed on page 528. It is indicated that spotting of this kind is most troublesome at 38°F. and below and, under some conditions, even 42°F. and below. To avoid pitting or cold-storage spot, two means may be employed, either the use of temperatures between 42 to 50°F., or the subjection of fruit to 70°F. from one to three weeks preceding entrance to cold storage at about 32°F. Good ventilation and circulation of air in cold storage will probably aid in the prevention of spotting, not only in cold storage, but in storage at ordinary basement temperatures.

SEPTORIA SPOTS

Spots probably due to species of Septoria have been found in northern Africa, southern Europe and a few times in California.

Spots on Mandarin.—In northern Africa the fruit spot occurs on mandarin oranges. It is described by Trabut (1898) as a greenish spot, in the middle of which are the black fruiting bodies (pycnidia) of the fungus. It is stated that this Septoria is clearly the cause of the disease. The fungus penetrates the tissue and produces a bad taste and odor in the fruit. In a later report, Trabut (1901) mentions large black spots on mandarin oranges, a few millimeters to 1 centimeter or more in diameter. The fungus causing it was referred to as *Septoria glaucescens*.

Spots on California Lemons.—A Septoria spot has been found in a few instances in California, on lemon fruits still on the trees, but it appears to be of rare occurrence. Barrett (1919) observed it in fruits from Bloomington section in 1915 (Fig. 177), and the same type of spot was found in the Orland section. These spots on the fruit in the orchard consist of very small sunken pits or depressions, evidently beginning when the fruit is green. As the fruit becomes light yellow in color, these spots remain greenish for a little while, but eventually become reddish. The green color persists for a short distance around the depressions. A species of Septoria was isolated by Barrett from these spots from the two localities mentioned above. Colonies on plates were composed of close, compact growth, 1/4 to 1/2 inch in diameter in ten days. Spores were borne in pycnidia and had one to three septa. Barrett's spore measurements from cultures on glucose potato agar were 18 to 30 by 2 to 3μ. These are somewhat longer than the recorded measurements for *S. citri* Pass, but are the same width.

Spots on Italian Lemons.—A Septoria fungus, probably *S. citri* Pass,[1] was found in abundance by Fawcett in spots on Italian lemons which had been three months in cold storage in Cincinnati in 1924. The measurements of the spores were about the same as those made by Barrett. The spots varied from mere specks to sunken, hard, dry areas involving one-third of the surface of the fruit.

The small spots were sunken and firm, buff brown to dark brown (Prout's brown to mummy brown on the surface, and ochraceous buff inside per Ridgway 1912). Two spots measuring ½ inch (12 millimeters) on the exterior were ⅔ to 1 inch (16 and 25 millimeters) in diameter in the inner rinds. Later they become darker. The larger spots or irregular areas were dark brown (Mars brown) to almost black in color. The entire rind over the affected areas was usually hard, firm and carbonaceous through to the juice sacks. A large percentage of the fruit in the lot examined was affected in this way. This type of rot was not seen in California lemons kept in storage under the same conditions.

---

[1] We are indebted to Dr. C. L. Shear for information as to the probable identity of this fungus.

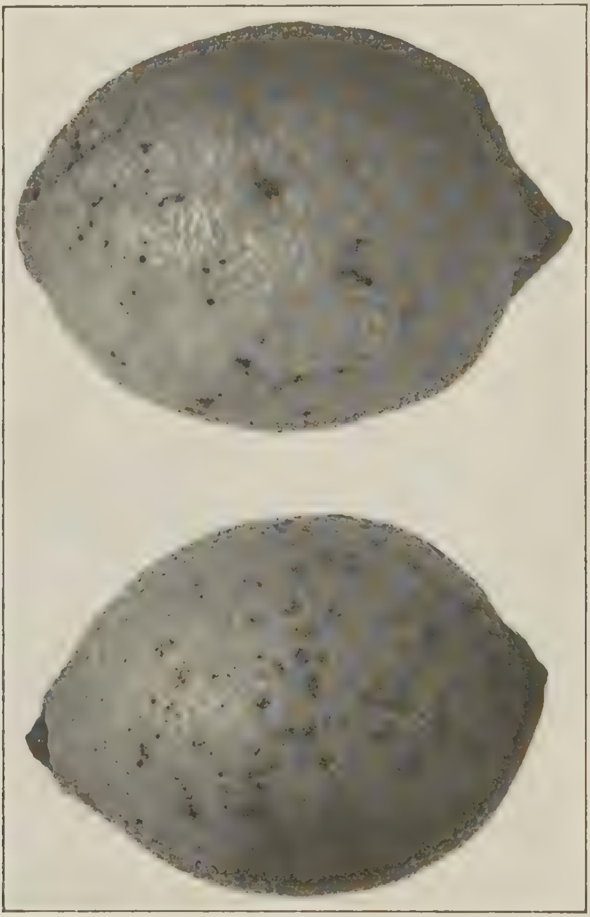

FIG. 177.—Septoria spots on California lemon fruits thought to be due to the fungus *Septoria citri*. (*Photo contributed by J. T. Barrett.*)

The fungus *Septoria citri* Pass. has been known for a long time in Italy (Comes 1891, Briosi 1908). It is described as having pycnidia, 50 to 80μ in diameter and one-septate spores 14 to 18 by 2 to 3μ. It was first described from diseased leaves in Italy. Other species of Septoria have been mentioned as occurring on leaves and fruit in Italy (Comes 1891, Voglino 1923) and in Australia[1] (Osborn and Samuel 1922).

BLACK SPOT

Black spot caused by the fungus *Phoma citricarpa* has been known in Australia since 1895, where McAlpine described it in detail in 1899. Within recent years it has also been found to be widely distributed in China. In the eastern hemisphere, there is no knowledge of its occurrence in countries other than China or Australia. It is not found in Japan, the Philippines and Java, nor is it reported from India or Mediterranean countries. It is entirely unknown in the western hemisphere to the present time (Fig. 178).

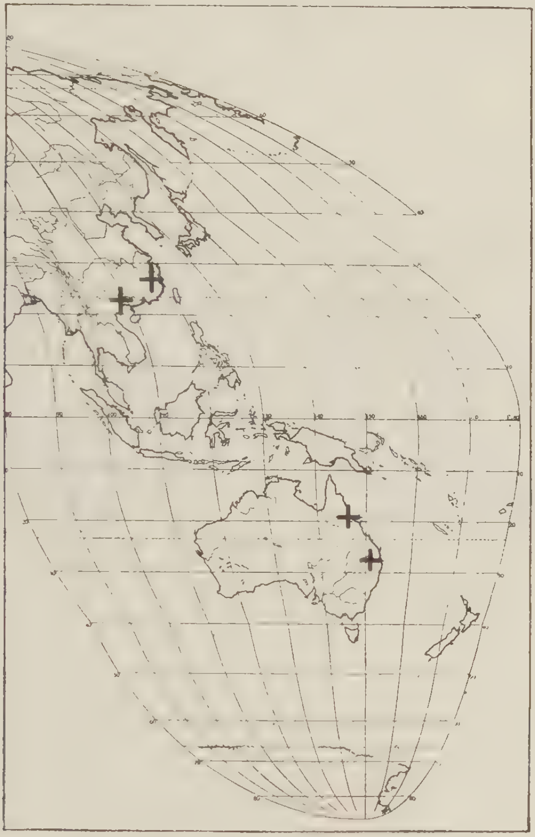

FIG. 178.—Map showing known distribution of black spot due to the fungus *Phoma citricarpa*.

Symptoms and Hosts Affected.—Black spot is found only on the fruits and is not known to affect the leaves, twigs or branches. The disease has been observed upon fruits of the sweet orange, *Citrus sinensis*, and the mandarin orange, *C. nobilis*. Pummelos, *C. maxima*, and calamondins, *C. mitis*, although seen in countries where the disease is common, as yet have not been found to be affected. Lemons, *C. limonia*, are reported by McAlpine to be affected. Data are not yet available as to the other species.

---

[1] Also in South America, India, France, Spain, Portugal.

Small, reddish-brown spots appear on the surface of the fruit; with increasing age these spots turn darker, becoming sometimes entirely black. The spot may be only 1/25 to 1/12 inch (1 or 2 millimeters) in diameter, but with time the area may spread to from 1/3 to 2/5 inch (8 to 10 millimeters) in diameter. As the spot matures, a reddish-brown, raised margin forms around the outer edges, while the center sometimes becomes depressed and assumes a light-tan or brownish color. Pycnidia sometimes show in the depressed, lighter-colored area; they are black and a mere fraction or a millimeter in diameter. The lesion not only occurs on the surface but extends into the skin tissue from 1 to as much as 2 millimeters. In this internal tissue, the lesion is usually lighter colored, similar to the reddish brown of a young lesion. The lesion has never been observed to extend into the flesh of the fruit, although rarely secondary rots, emanating from a black-spot lesion as the original point of infection may progress into the flesh (Fig. 179).

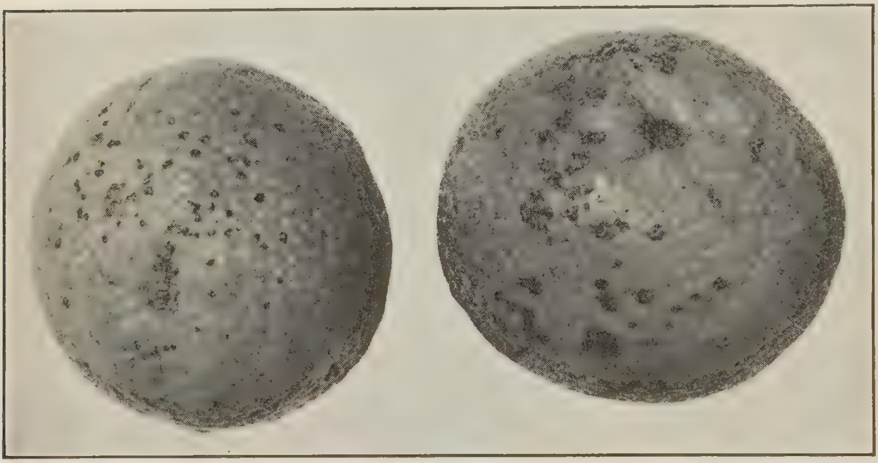

FIG. 179.—Black spot on fruits of a Chinese mandarin orange variety. The spots are caused by the fungus *Phoma citricarpa*, McAlpine.

The disease is not abundant on fruits in the orchard, but seems to develop more readily while they are in storage or in transit to markets. Fruits have been shipped entirely unblemished, which, on unpacking one month later, were found severely affected by this black spot. The injury to the crop is much the same as that of Citrus canker on fruits and is due to a blemish which lessens its selling value. In a very few cases, the black-spot lesions afford an entrance for rot fungi, but such cases are rare.

The Causal Agent.—The fungus *Phoma citricarpa* was first described by McAlpine (1899) in Australia and was found constantly associated with the black-spot lesions in that country. In China, this fungus was isolated by Lee (1920*c*) in pure cultures, and inoculation experiments showed the pathogenic relationship of the fungus to the black-spot lesions.

The fungus grows slowly on the artificial media tried and is not always easily isolated because of the ease with which secondary fungi may outgrow it. Beef agar +1 (Fuller's scale), glucose agar +1, and potato plugs have been used for culturing this fungus; on all of them, the fungus makes a restricted growth. The early mycelium is grayish, but the colony soon becomes dead black due to the formation of pycnidia; the colonies are small and restricted (Fig. 180). Pycnidia appear within six or seven days after planting and are abundant, black, spherical and with pores indistinct.

Under the microscope, the young hyphæ are hyaline and distinctly septate, but with age the hyphæ become dark olive brown, closely septate, twisted and swollen. Spores are borne apically on slender, hyaline conidiophores and are hyaline, single celled, smooth and thin walled, ovate, sometimes becoming almost pyriform, noticeably granular (Fig. 180); from cultures they vary in size from 9.25 to 12.25 by 5.5 to 8.1μ. Spores are not formed profusely. The diagnostic features are the black, carbonaceous, restricted growth in cultures and the thin-walled, granular and somewhat individualistic spores. The best determination of the fungus is its pathogenicity on sweet oranges which may be visible in from fifteen to twenty days.

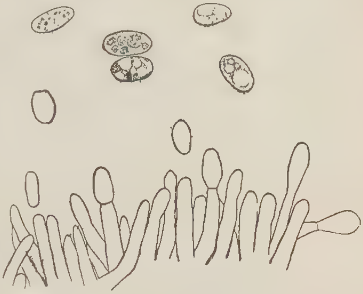

FIG. 180.—Conidiophores and conidia of the black spot fungus, *Phoma citricarpa*, ×500.

Contributing Conditions and Prevention.—There are no experimental data on the temperature or moisture relationships of the fungus, but from the occurrence of the disease in China and Australia, the inference would seem to be that it is primarily a disease of temperate countries. Experimental data are available to show that fruits are susceptible only when they approach maturity, and that green immature fruits are not susceptible.

Since the fruit is susceptible only as it approaches maturity, it would seem possible that preventive spraying of orchard trees, as the fruits are ripening, could be made effective at low cost. However, there have been no spraying investigations against this disease to the present time. For countries where the disease does not yet occur, as in the Philippines, Japan, Java, India, the Mediterranean countries and the western hemisphere, the best and cheapest prevention is entire exclusion. Entire exclusion would seem to be especially applicable to California and Florida where temperatures and climatic conditions are in many ways similar to China and Australia, and where the susceptible varieties and species of Citrus are extensively grown.

CANCROSIS OR CITRUS CANKER ON FRUITS

This disease, due to a bacterial organism, *Pseudomonas citri*, has received much attention in recent years because of its spread from the Orient to the western hemisphere, and because of the extensive but successful fight against it in Florida where, before its serious nature was discovered, it had already gained a firm foothold.

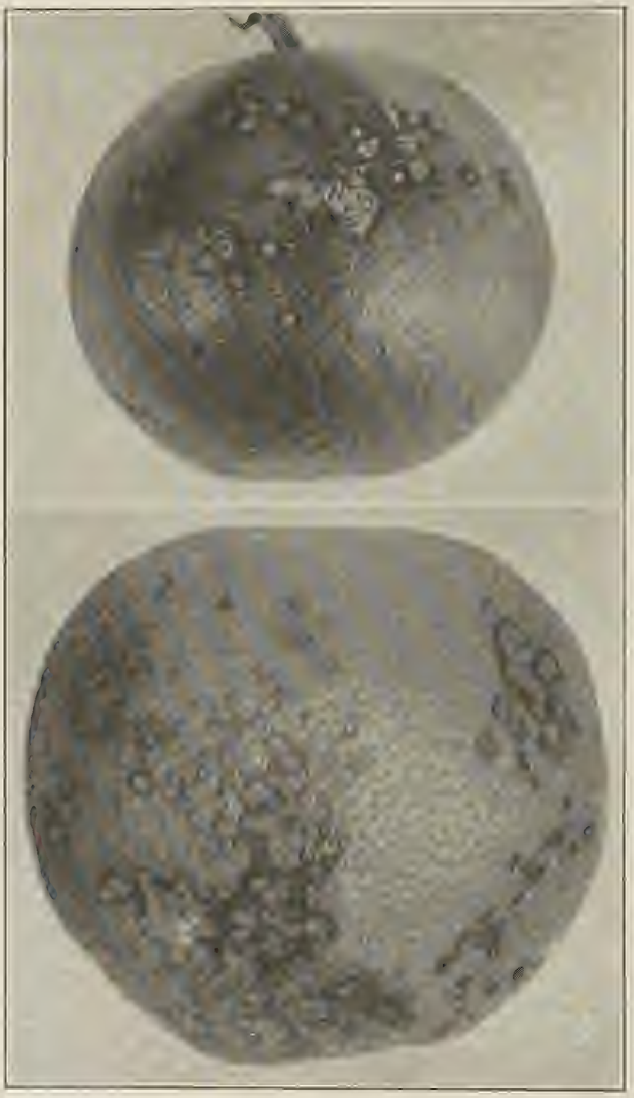

FIG. 181.—Showing serious blemishes caused by Citrus canker on fruits: A, on Pineapple orange; B, on Ellen grapefruit. See also colored illustration, Fig. 58.

The history, distribution, symptoms on leaves and twigs, contributing conditions and control are discussed in Chap. XI under Twigs and Leaf Diseases.

Symptoms on Fruit.—Individual canker lesions have much the same appearance on the fruits as on the leaves. These lesions become spongy, rough eruptions involving the surface layers and some of the underlying tissue. Rapidly developing cankers may have a white spongy tissue, while slowly developing ones may be tan colored. There is usually a glazed, oily-appearing margin as in lesions on leaves. Lesions on fruits commonly do not exhibit the yellow halo shown on the leaves. The crater-like appearance is more noticeable on fruits than on leaves. This is readily distinguished with a hand lens, the margins of the lesions being elevated and a depressed area being inside, as shown in Figs. 58, 59, 181. Badly affected fruits have a scabby or scurfy appearance as is shown in Fig. 181. Canker upon the fruits is a lesion of the rind only, and does not penetrate into the flesh of the fruit.

There is a very considerable difference in the appearance of cankers on the fruits of the different species. Cankers on pummelos and grapefruits are large and, although at first elevated, may become somewhat sunken as the fruit develops. To a slightly lesser extent, this is also the case with the sweet oranges. Cankers on lime and lemon fruits are somewhat smaller, rarely become sunken and are more decidedly elevated than on any of the other hosts. Upon Satsuma fruits, cankers are rather minute and may be easily mistaken for scab. At certain stages, Satsuma fruits are readily infected and probably are the most readily infected tissues of that species.

LEPROSIS OR NAILHEAD RUST

This disease is less common on fruits than on twigs or branches. In rare instances, it also affects leaves. The sweet orange, *Citrus sinensis*, is the principal species susceptible to it. Attention has been called to it principally in Florida, where it occurs in orchards only in the middle portion of the state, as shown by map (Fig. 66). Details regarding the disease on branches and twigs will be found in Chap. XI (see also Figs. 38, 67, and 68).

Symptoms on Fruit.—On the rind of green fruit, the spots first appear either as round yellowish areas, which soon become reddish to brown, or as slightly sunken rings with an interior green area. These usually begin to appear on the fruit in July and August in Florida, four to five months after the bloom is shed. Twigs, however, are usually six to nine months old before spots appear on them. The earliest record by Fawcett (1911*b*) of spots on the fruit was June 29. By September the spots are quite conspicuous, and by November they are well formed. As the fruit approaches maturity, and while it is still green, the rings became sunken

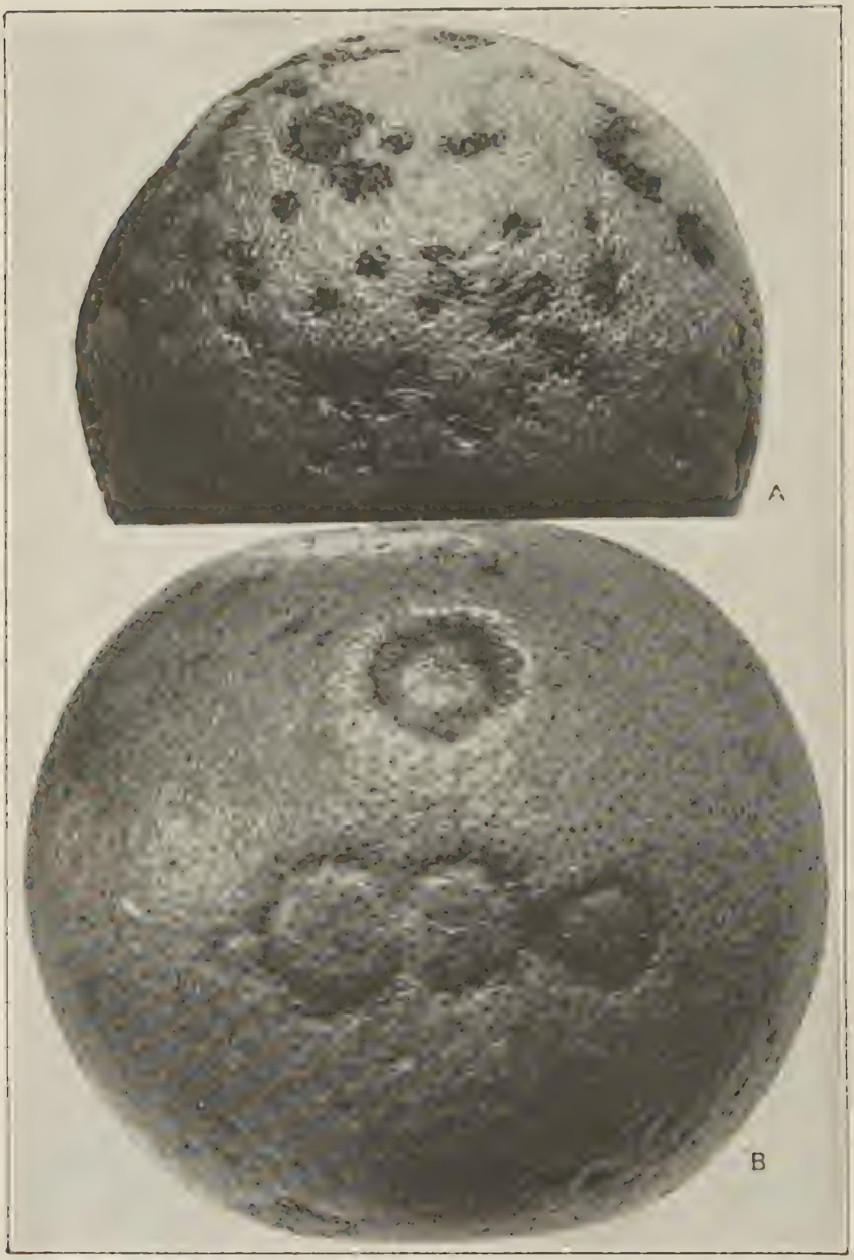

FIG. 182.—Leprosis or nail-head rust spots as they occur in Florida on orange fruits. A, Small hard spots; B, spots in the form of depressed rings. See Figs. 38 and 67 for spots on twigs.

and brown, while their central portions usually remain green longer. In some spots, the centers are marked by a ruptured point which suggests infection from an insect puncture. The fruit colors rapidly, and the portion inside the ring sometimes remains green for a short time after the rest is colored. Many spots are also formed which are not ringed (Fig. 182). Such spots may have a chestnut-brown center with a lemon-yellow halo which fades imperceptibly into the normal green of the immature fruit. The spots vary somewhat with the variety of the orange and the thickness of the rind. The spotted fruits color prematurely and tend to drop before the picking season. The spots vary from $\frac{1}{8}$ to $\frac{3}{5}$ inch (3 to 15 millimeters) in diameter, but are mostly $\frac{1}{5}$ to $\frac{2}{5}$ inch (5 to 10 millimeters) across. They rarely extend deeply into the rind, but affect only the outer portion. Spots rarely occur on the leaves. When present, they are somewhat similar to those on the twigs. The affected leaf tissue becomes hard, glazed and brittle, and is surrounded by a yellowish border.

Leprosis on the fruit differs from canker in the following points: The spots are not spongy nor raised above the surface. Leprosis seriously affects only the sweet-orange fruits, while canker most seriously affects grapefruit and also affects many other varieties not attacked by leprosis. Leprosis spots on the twigs are more glazed and hard, not spongy nor so prominently raised from the surface. For a discussion of other features of the disease including control measures, see page 231.

VERRUCOSIS OR SCAB

Verrucosis or scab has attracted much attention, especially in Florida and the Gulf states, where it causes serious injury to grapefruits, Satsumas, some of the mandarin-orange varieties, lemons and sour oranges. It is, at present, widely distributed, but has not persisted in California, even though badly infested sour-orange stock from Florida is known to have been planted there in former years before the present quarantine laws went into effect. Scab has probably spread from Japan, where it is now known to have existed for a long time, to most parts of the world where the climate is suitable for its occurrence.

History and Distribution.—The first account of this disease in the United States was published by Scribner in 1886, and it has since been investigated by various workers, Swingle, Webber, Fawcett, Grossenbacher, Hesler, Peltier, Winston, Jenkins and others. The causal fungus was first isolated in 1906 and was shown by inoculation experiments to be capable of producing the disease under suitable conditions of moisture and temperature (Fawcett 1907, 1912*a*, 1916*b*, 1921*b*).

Citrus scab is now regarded by Japanese pathologists as a disease that was present in Japan from ancient times (Tanaka 1923). It was spoken of by the earlier Japanese writers as a characteristic of a certain kind of orange rather than a disease. The early history of scab has been collected by Tanaka from various sources, Nishida (1903*a*), Ideta (1911) and Onda (1905). Tanaka states that the native Japanese names for scabby oranges were Abata Mikan (smallpox orange) and Kasa Mikan (syphilis-scab orange). The disease became known as Sôkabyô (scab disease), a name proposed by Nishida (1903*b*). Both Citrus scab and Citrus canker were for a time included in this name, but soon after Citrus canker spread to America and was found to be a separate disease, the two diseases were separated in Japan by the terms Marugata Sôkabyô (round scab disease) and Kankitsu Kwaiyôbyô (canker disease of Citrus).

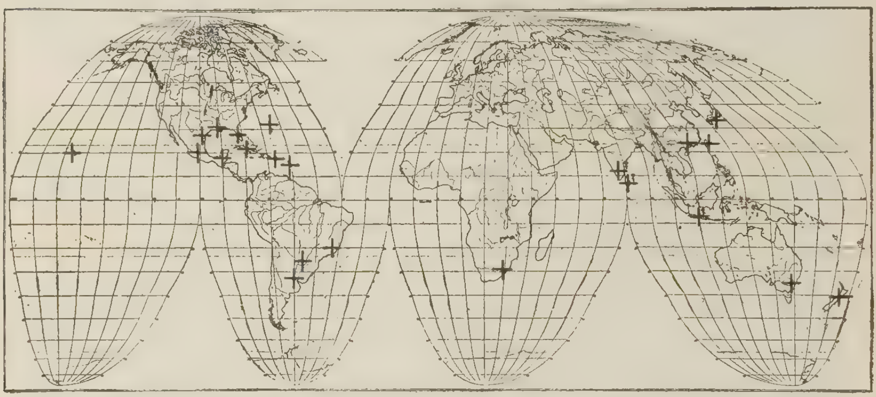

Fig. 183.—Map showing the known distribution of Citrus scab.

Specimens of Citrus-scab lesions collected as early as 1863 at Nagasaki were seen by Lee (1918*c*) in the Hongkong Botanical Gardens. This fact, taken in conjunction with the observation that scab is widely distributed in southern China, appears to indicate that the disease was indigenous to the Orient.

According to Tanaka (1923), the earliest mention in Japanese literature is probably by Yoshinyuki Murase in a manuscript work called "Nankai Hofu" (oranges of South Sea district), written in 1818. The disease was given little attention, however, by Japanese Citrus growers until about 1905. At this time, it began to be recognized as injuring the quality of Satsuma oranges for export trade, and Hori (1916) showed that it could be controlled by Bordeaux spray.

Scab appears to have been unknown in America until discovered about 1885 near Ocala, Fla., on sour-orange nursery stock. It was reported on lemon trees in 1886 and gradually spread to all parts of the orange-growing regions of Florida and later to the Gulf states of Louisiana, Alabama, Mississippi and Texas. Underwood (1891) speaks of

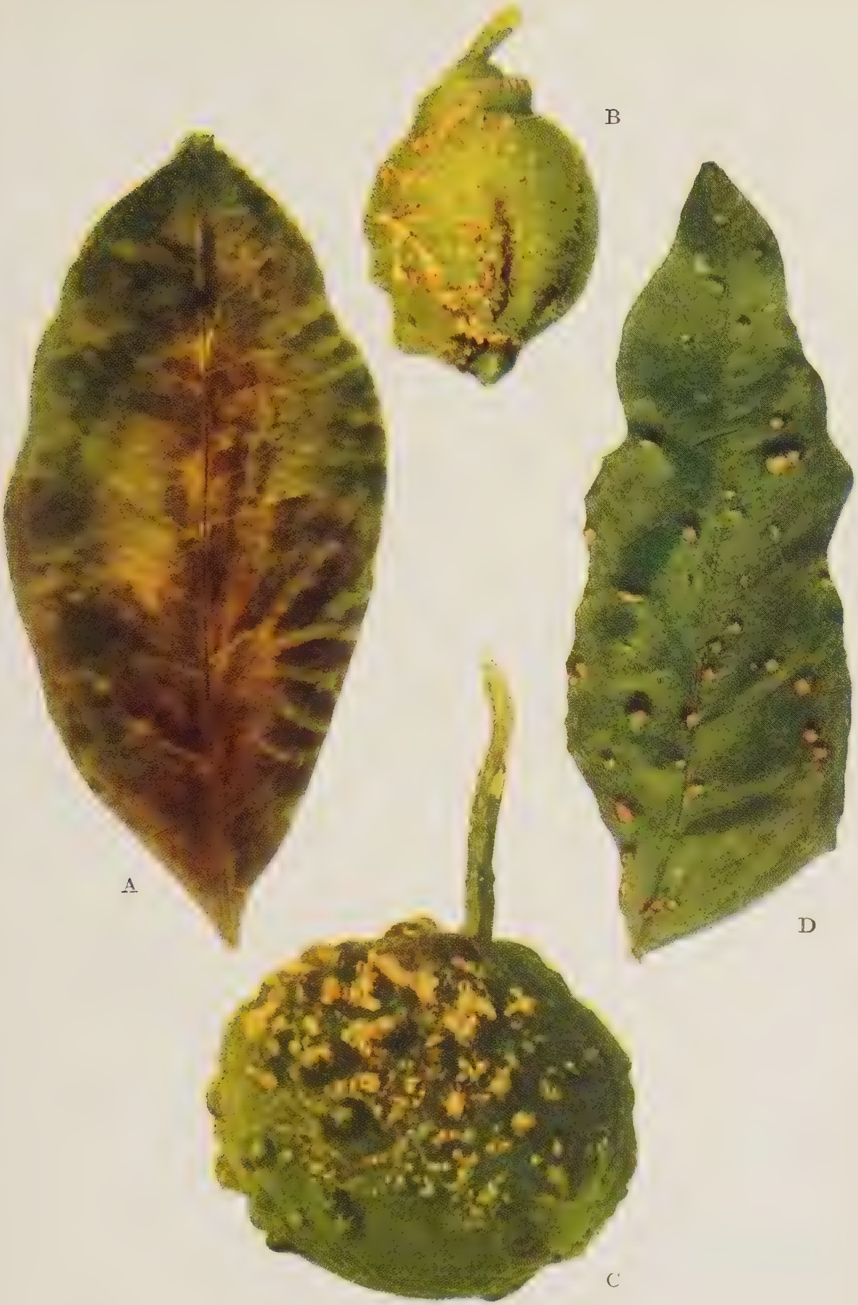

FIG. 184.—Scab and Phyllosticta leaf spot. A, Leaf of Satsuma orange in Japan showing spots causing a leaf drop associated with a species of Phyllosticta. B, Scab or verrucosis on young lemon fruit. (*After Swingle and Webber* (1897)). C, Scab on Satsuma orange fruit. D, Scab on Satsuma orange leaf.

(*Facing page* 486)

scab as a widespread disease in Florida. A detailed account of the disease was published by Swingle and Webber (1896), who were also the first to show that scab could be controlled by spraying with Bordeaux or ammoniacal solution of copper carbonate.

Scab assumed commercial importance in Florida in disfiguring lemon fruits, and the almost complete abandonment of lemon growing before 1910 in that state was probably due, in great part, to the severity of this one disease.

Scab has now spread to many Citrus-growing regions of the world, especially those in which the temperature and humidity conditions are suitable (Peltier and Frederich 1924*b*). It has not been reported in California or Arizona, and there is no authentic report of its occurrence in the Mediterranean countries. Some of the illustrations of ruggine bianca on lemons in Sicily published by Briosi and Farneti (1904) somewhat resemble scab, but we believe that this is a different disease. Swingle (1897) failed to find true scab in Sicily, and one of the authors in visiting Sicily and south Italy in 1923 did not find evidence of it on lemons there. Scab has recently gained a foothold in Argentina, South America, as reported by G. Fawcett (1920). It was first noticed at a single station in Tucuman and rapidly spread from this point to various districts. It has also been recently reported in Paraguay by Spegazzini, and P. H. Rolfs writes that it occurs in Brazil.

The known distribution of scab is shown on the map (Fig. 183).

Symptoms.—Scab is found on leaves and twigs as well as on the fruit, the outstanding characteristics of the disease being the formation of irregular, raised lesions commonly referred to as warts or scabs.

Lesions on Fruit.—On fruit, the lesions appear either as corky projections with distinct distortion of the fruit, such as are frequently seen on lemons, sour oranges and Satsumas (Fig. 184), or as irregular, slightly raised scabs without much final distortion, as in certain varieties of grapefruit. On ripened grapefruit, the skin in the region of the scabby areas tends to remain green. On young green fruit, the lesions exhibit more or less the same color variation as that noted for leaf lesions, though it is possible that the colors may be more or less characteristic for a given variety. Winston (1923) notes that lesions on young grapefruit are cream colored to pale yellow orange, and A. E. Jenkins writes that

> . . . young bitter-sweet and Satsuma oranges examined each presented a characteristic appearance; the border of lesions on bitter-sweet oranges was pinkish buff, and the central area, where the fungus was fruiting, umber; on the Satsumas, various shades of red were represented, Pompeian, ocher, mineral and dark mineral red per Ridgway.

The surface of the lesions of considerable size in some cases may become broken up into small fine scabs and may resemble some of the forms of scurf due to other causes. In such cases, it is not always easy to diagnose with certainty.

If the development of the lesions is studied from their earliest appearance, they are first seen as minute dots which become raised protuberances. These lesions become more conspicuous as the fruit enlarges. Some lesions result in abnormal outgrowths on the apices of which the scabby tissue is located. Other lesions arising close together coalesce to form scabs of greater extent with irregular, rough surfaces occupied by the tissue invaded by the organism (Fig. 185).

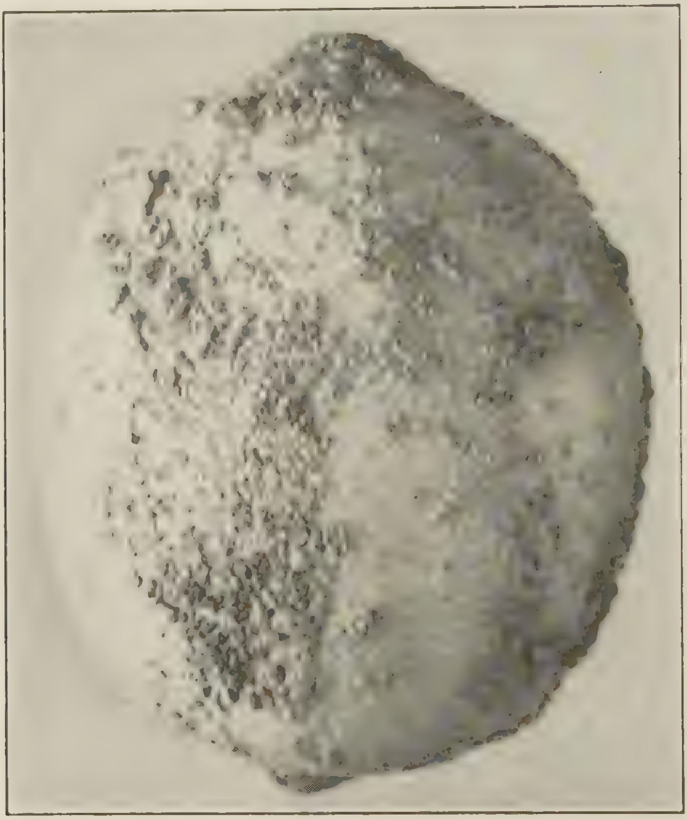

FIG. 185.—Citrus scab on mature lemon natural size. (See also Figs. 61–63, 184 for effects on leaves.) (*Photo contributed by Jenkins* (1925).)

Lesions on Leaves.—On the leaves[1] before they have unfolded, the lesions may be evident as small semitranslucent dots, soon becoming sharply defined papillary elevations, flat or somewhat depressed at the center. The color of the lesions is considerably varied; at first, various bright colors are exhibited, often in the same lesion; as the leaves age, the color becomes dull and inconspicuous. Young lesions are often salmon buff[1] or flesh ocher. The central areas of slightly older lesions are drab, due to the formation of tiny tufts—the conidiophores and spores of the pathogene. Somewhat older lesions may range from vinaceous drab to drab or dark olive gray with a fine velvety surface formed by the fruiting structures of the causal fungus. This growth may be present for a considerable length of time, gradually disappearing as the leaf ages. On old lesions, it often remains pinkish or rose colored, presenting a smooth, scarred appearance. With the hardening of the leaf, the lesions enlarge, becoming rough, corky and wartlike and occasionally disintegrating to some extent; they are then tan or dull colored and present an unsightly appearance, due to the accumulation of dust and the growth of saprophytic fungi over their surfaces.

---

[1] The description of the disease on the leaves was contributed by Anna E. Jenkins of the Bureau of Plant Industry, U. S. Department of Agriculture.

The lesions occur on either surface of the leaf, particularly on the under side, where they are more numerous. They may be single or irregularly grouped; occasionally, they are arranged in a small ring or may be confluent, forming a more or less extensive and somewhat thickened region. In confluent lesions, the individual lesions may remain distinct, each with its drab center composed of fungus growth as described above, or they may appear as a continuous velvety surface. The lesions may not be visible on the opposite side of the leaf or they may penetrate it. On succulent leaves, the tissue in the region of confluent lesions, particularly, is sometimes definitely necrotic. On these brown areas, the lesions show no bright hues, but are indicated by the fine velvety growth made up of conidiophores and great numbers of spores. The dead tissue soon breaks away, leaving irregular openings or broken leaf margins. On leaves of Satsuma, necrotic areas are rather common, the cracking and breaking away of the dead parts giving a ragged shot-hole effect as shown in Fig. 63.

Distorted, wrinkled, drawn or stunted leaves are also characteristic evidences of the disease. The deformations often consist of crater-like elevations or hollow conical outgrowths bearing lesions at their apices. In the region of the scab lesions, the leaf may be noticeably etiolated, gradually assuming normal color as the leaves age and harden. The discolorations may be nearly white at first, later, on the upper surface, exhibiting bright-green color as oil yellow, which shades to the natural leaf color. A grapefruit leaf examined showed vivid green discolorations flecked with apricot-orange dots above, below which were confluent lesions of vinaceous cinnamon and vinaceous drab. Diseased leaves about to fall may be considerably blanched.

---

[1] The color determinations (Ridgway 1912) were made from fresh leaves of grapefruit, lemon and sour orange, at Orlando, Fla., by F. R. Cole, Bureau of Entomology, and A. E. Jenkins, Bureau of Plant Industry, U. S. Department of Agriculture during the spring of 1925.

Age of Tissues Affected.—Winston (1923) has shown by a large number of inoculations on fruit of different ages that, under Florida conditions, grapefruit is susceptible from its earliest formation, just as the petals fall, up to the time it reaches about ¾ inch in diameter, after which it is immune to attack. His evidence indicates that the susceptibility decreased progressively with the increase in the size of the fruit.

With leaves, the susceptibility is greatest as they emerge from the bud and decreases progressively until they reach about ½ inch in width, after which they are immune.

The Causal Agent.—Scab is due to a minute parasitic fungus, *Sporotrichum citri* Butler (Doidge and Butler, 1924) (*Sphaceloma fawcettii* Jenkins) (Jenkins 1925). Only the imperfect stage of the fungus is known. It was first isolated in 1906 by Fawcett (1907). At that time, however, it was incorrectly assumed to be *Cladosporium citri* Massee. The erroneous use of the names, *C. elegans* Penz. and *C. citri* Penz., in connection with the disease was pointed out by Fawcett in 1910 (Fawcett 1910*b*). Doidge and Butler (1924) have suggested the name *Sporotrichum citri* because of certain resemblances to parasitic species of Sporotrichum of animals.

Recently, the fungus has been carefully studied by Jenkins (1925), who finds that the cultural and morphological characteristics of this fungus suggest close relationship to the anthracnose fungus of the grape, *Sphaceloma ampelinum* DeBary, and *Glœosporium venetum*, the imperfect stage of *Plectodiscella veneta* (Sacc.) Burkholder.

Characteristics of the Fungus.—On standard nutrient agar with the addition of 2 per cent glucose, there is first a tortuous growth of minute colorless hyphæ which soon coalesce into a kind of stroma. In three or four days, the mycelial growths become visible to the unaided eye. It may be ten to twelve days before the mycelia are 2 to 4 millimeters in diameter, hemispherical, flesh colored with a yellowish-brown to reddish-brown tinge. The central mass becomes raised, conical and firm and is sometimes covered with a tenacious, viscid or gummy substance. Miss Jenkins writes that "this substance may cover the exposed stromatic growth in the lesions under natural conditions, and that small granules are often seen embedded in it both in natural lesions and in cultures; in twelve-day-old cultures on potato dextrose agar plants grown at constant temperatures of 10, 15 and 20°C., the substance was present on those at 10 and 15°C. and nearly lacking on those at 20°C. Parallel cultures of the grape and raspberry anthracnose organisms showed a similar development of the gelatinous covering, although, with the grape fungus, it was produced in considerably larger quantity than on those of the other two; at 10 and 15°C., it formed a thick, clear, glistening covering over the culture. The margins are fringed by small outgrowing hyphæ."

Mycelia that are not crowded may grow to a maximum diameter of 6 to 8 millimeters. The central part is made up of close septate hyphæ in a fairly firm gelatinous mass. When bits of this gelatinous mass are transferred to certain other media, such as sweet-potato plugs or sterilized orange twigs, a somewhat looser growth of mycelium tends to form. The growth is very slow and tends to produce a piled-up tough mass (Fawcett 1912*a*). The growth of this interesting fungus has also been carefully described on a number of other media by Winston (1923). According to him, its most characteristic and striking growth is on glycerine agar, on which, in fifteen days, the mycelia are 5 millimeters in diameter, raised and covered with dense, short, woolly hyphæ, the fungus itself being vinaceous drab, giving the surrounding medium a

Carenthian purple to dull Indian purple color (Ridgway 1912). Illustrations showing the striking similarity between the Citrus-scab fungus and the apparently related grape and raspberry anthracnose organisms when grown on beef agar, as well as their differences when grown in parallel cultures on several other kinds of artificial culture media, were exhibited by Miss Jenkins in connection with the presentation of her recent paper (Jenkins 1925).

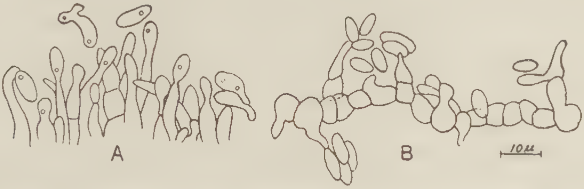

FIG. 186.—Spore formation of the Citrus scab fungus, in cultures. A, Spore-bearing bodies (conidiophores) which had arisen from a stromatic growth bearing spores (conidia) at their ends. B, Conidiophores and conidia arising from a mycelial strand of short hyphal cells. (*After Jenkins* (1925).)

The spores are formed on the tips and sides of simple, unbranched (occasionally branched), outwardly extending aerial hyphæ (Fig. 186A). They are formed quickly and rapidly in cultures under certain conditions of temperature when transferred from a fairly dry to a moist atmosphere. Miss Jenkins writes that in her cultural studies of the Citrus-scab fungus, "spores were obtained by transferring small portions of culture on potato dextrose agar to freshly poured corn-meal agar plates, and that Fig. 186A was drawn 24 hours and Fig. 186B 30 hours after making such a planting. In these cultures, it was observed that these spores might remain attached to the conidiophores germinating *in situ*, or that they might be immediately detached. In the growth of aerial hyphæ, the cells may become septate, sometimes giving the appearance of a chain of spores."

The spores are probably ejected with considerable force from the ends of the hyphæ. They have been observed by Fawcett (1921*b*) in culture media to be located as far as 210μ horizontally from the tips of the outermost hyphæ in an undisturbed petri-dish culture. An ejecting force is perhaps indicated by the fact that all the spores which had been shed were located at some distance, leaving a clear space between the mucelial disk and the ring of spores. This phenomenon was also noted when the fungus was grown in water preparations next to a floating, young, sour orange leaf. It was also noted by Jenkins in 1924, not only in connection with her transplantings of the Citrus organism but also with those of the apparently related (Jenkins 1925) grape anthracnose fungus. The photomicrographs in (Fig. 187) show both conidiophore and spore production at the end of a sixteen- and a twenty-four-hour interval. The spores

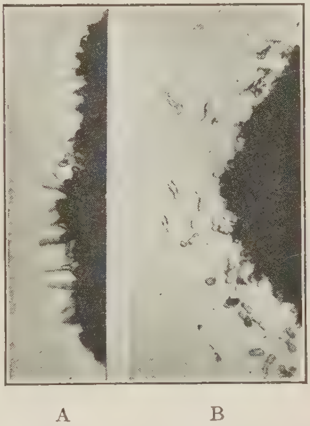

FIG. 187.—Photomicrograph of the Citrus scab fungus from transplanting placed on corn meal agar; A, after 16 hours showing conidiophores and spores on margin of the culture; B, after 24 hours showing spores that have been apparently forcibly ejected from the conidiophores. Germinated spores are also present. Magnified about 250 diameters. We are indebted to Miss Anna Jenkins for this illustration which was used to illustrate her paper (Jenkins, 1925) presented at the annual meeting of the Botanical Society of America, Washington, D. C., Dec. 29, 1924.

are seen lying about on the surface of the medium at various distances from the planting, some of them having germinated.

Jenkins (1925) has described the Citrus-scab fungus as follows:

"*Sphaceloma fawcetti* (*Cladosporium citri* Fawcett, not Massee). Acervuli solitary or confluent, subcircular, chiefly less than 1 millimeter in diameter, on leaves intraepidermal, becoming erumpent, pseudoparenchymatous at base, may also extend to the underlying host tissue, in this region mainly plectenchymatous; conidiophores arising perpendicularly from surface of stroma, standing close together, cylindrical, apex sharp pointed, blunt apiculate or obtuse, one to three celled, hyaline, but may become dusky, principally 12 to 22 by 3 to 4μ; conidia acrogenous, also pleurogenous (observed in culture), usually developed singly, often in succession from the same conidiophore (observed in culture), oblong ellipsoid, slightly reniform or ovoid, ranging from 5 to 10 by 2 to 5μ, usually 6 to 8.5 by 2.5 to 3.5μ, often biguttulate, one oil drop at each end, continuous, hyaline, sometimes becoming elongated or swollen and one septate and dusky."

Contributing Conditions.—If the spores are forcibly ejected from scabs in the open, as they appear to be in cultures, this feature would aid in their dissemination by getting the spores away from the scabs into air currents which would carry them from place to place. The minute spores on the surface of scabs are probably blown by wind, carried by insects, rain and heavy dews. The severity of scab is dependent upon a special set of conditions, even when the inoculum is present for dissemination. Among those of importance are: (1) a susceptible species or variety, (2) young unmatured tissue, (3) sufficient moisture and (4) a suitable range of temperature (Fawcett 1921*b*). All these conditions must be fulfilled before a serious outbreak of scab may be expected. The first two conditions have to do with the host plant. If we have an inherently susceptible host, such as Satsuma, lemon, sour orange or grapefruit, the causal fungus will be able to infect and produce scab only on young immature leaves, shoots or fruit. The presence of the third condition, moisture in contact with the surface, is necessary for a sufficient period for the spores to germinate and penetrate the host. Along with these previous conditions, it has been found that temperature is also very important, a range between about 59 and 73.4°F. (15 and 23°C.) being essential.

In experiments by Fawcett (1921*b*) under controlled conditions, infection of sour-orange leaves took place only between 60.8 and 73.4°F. (16 and 23°C.) even under ideal conditions of moisture and growth; and in experiments by Peltier and Frederich (1924), almost the same range 59 and 73.4°F. (15 and 23°C.) was indicated. Peltier's observations of the occurrence of scab in the orchards under Alabama conditions have indicated that this is the important range for serious scab infection, provided the other necessary conditions are present. The interacting factors and conditions influencing the prevalence of Citrus scab have been analyzed in detail by Peltier. After discussing the importance of the factors of young tissue, moisture and temperature, he points out that under Alabama conditions any environmental conditions that induce a large amount of spring growth with subsequent slow maturation, especially during a period of optimum conditions of moisture and temperature, will result in a severe attack of scab; while the reverse, namely, a quick-growing season with higher temperatures and lower humidities, tends to bring scab escape. Grossenbacher (1916) and Stevens (1918*a*), in discussing the factors favorable to scab under Florida conditions, have pointed out the relation of cool wet seasons at the time of the first flush of growth to severe outbreaks of scab. Swingle and Webber (1896) and Winston (1923) have emphasized especially the importance of moisture under Florida conditions.

In the light of these necessary conditions for the occurrence of scab, a good explanation appears to be at hand why the disease does not occur in California and the Philippines. It has been known to have been brought into California on nursery stock with thousands of sour-orange trees before the strict quarantine law was passed, but the new foliage came out free from attack. An analysis by Peltier and Frederich (1924*b*) of the monthly mean temperatures, rainfall and number of rainy days of Los Angeles, Cal., and Manila, as compared to Mobile, Ala., and Nagasaki, show that the mean temperature of 77 to 83.5°F. for Manila, P. I., is above the range for infection, while the rainfall in a locality like Los Angeles is very low at the time when the tissues would be susceptible. Citrus trees in warmer locations in the Philippines would presumably escape because of high temperatures, even when moisture and other conditions were favorable, while trees in southern California would escape for a different reason, namely, because of too little precipitation at the time when the other external and internal conditions are favorable. Peltier and Frederich (1924*b*) have concluded that scab would be inhibited in any region whenever the mean monthly temperature of 75°F. or above prevails, and that it would not be serious in regions having a well-defined dry season, especially when the dry season coincides with the higher temperatures, as in California.

Susceptibility of Varieties and Species.—The plants attacked by Citrus scab appear to be confined to the order Rutaceæ, and so far as known to the subtribe Citrinæ, with one exception, that is, *Claucena lansium* Sk. The fungus reported on avocado as probably the same as that causing Citrus scab is being critically studied recently by A. E. Jenkins (1925), who considers it to be a different species and is describing it as such. The varieties and species of Citrus and their near relatives vary greatly in their susceptibility to Citrus scab. Winston (1923) discusses especially the susceptibility of the commercial varieties under Florida conditions, and Winston, Bowman and Bach (1925), as a result of studies and observations over a period of eight years, give the susceptibility of an extensive list of rutaceous plants. Many of the varieties and species of especial interest may be roughly grouped as to their susceptibility into four classes in accordance with information in the last two publications mentioned.

1. Those severely attacked:
    - Sour orange, *Citrus aurantium*
    - Rough lemon, *C. limonia*
    - Common lemon, *C. limonia*
    - Calamondin, *C. mitis*
    - Pointed-leaved papeda, *C. hystrix*
    - Tangelo, *C. maxima* × *C. nobilis deliciosa*
2. Those moderately attacked:
    - King orange, *C. nobilis*
    - Satsuma, *C. nobilis unshiu*
    - Tangerine, *C. nobilis deliciosa*
    - Grapefruit (except Royal and Triumph), *C. maxima*
    - Trifoliate orange, *Poncirus* (*Citrus*) *trifoliata*
    - Citrange, Rusk, *C. sinensis* × *P. trifoliata*
    - Sweet lemon
3. Those rarely attacked:
    - Sweet orange (in part), *C. sinensis aurantifolia*
    - Kumquat, oval, *Fortunella margarita*
    - Tahiti lime
4. Those apparently immune:
    - Citron, *C. medica*
    - Mexican or Key lime, *C. aurantifolia*
    - Sweet orange (in part), *C. sinensis*
    - Kumquat:
        - Round, *Fortunella japonica*
        - Meiwa, *F. crassifolia*
        - Wild, *F. hindsii*
    - Round-leaved papeda, *C. hystrix*
    - Australian finger lime, *Microcitrus australasia*
    - Royal and Triumph grapefruit
    - Cleopatra mandarin

The idea that Mexican limes are susceptible in Florida is probably due to the following comment by Swingle and Webber (1896): "Scab or a disease closely allied to it occurs on very young fruit of the lime, causing the fruits to fall while still very small. It has not been found on the older fruit or leaves of this species." This falling of the fruits when quite young is characteristic of anthracnose due to *Glœosporium limetticolum* Clausen. At that time, the anthracnose of limes had not been studied. Most of the so-called limes appear to be immune or highly resistant to scab except Kusaie lime and sour Rangpur lime, both of which are quite unlike the other limes. The Tahiti lime appears to be slightly susceptible to scab.

Others highly resistant or immune are the sweet orange, citron, three species of kumquats, Cleopatra mandarin, Royal and Triumph grapefruits (probably hybrids), round-leaved papeda and Australian finger lime.

The sweet-orange group, as a whole, is highly resistant, but some varieties are occasionally slightly attacked. The *C. nobilis* group, as a whole, is moderately attacked, except the Cleopatra mandarin before mentioned. The lemons, as a whole, are severely attacked except the sweet lemon and Chinese dwarf lemons, which may be hybrids and are moderately attacked.

Control.—Many experiments, especially along the lines of spraying, have been conducted for the control of Citrus scab in Florida, first, by Swingle and Webber as early as 1894, and later, by Fawcett (1912*a*), Grossenbacher (1916), Winston (1923) and others, and in Porto Rico by Tower (1923). Because of the nature of the disease, the control methods have taken the line of prevention rather than direct treatment. Fairly effective methods of prevention by spraying have been worked out. In all the spraying experiments, the copper sprays, such as Bordeaux mixture, have been found most effective. The objection to this form of spray, however, has been that, under Florida and West Indian conditions, it also kills the fungi that parasitize and control the scale insects. This disadvantage has been considerably overcome by the recent use of the Bordeaux-oil mixtures and, where necessary, a later follow-up spray with oil to keep down the scale insects. Lime-sulfur sprays have also proved of value but are much less effective than Bordeaux.

While recent spray programs differ somewhat as to the practical details of bringing about the necessary protection against scab without undue expenditure, all agree as to the main principles involved.

As has been pointed out previously, the scab fungus affects only young immature tissue, even when other conditions are favorable. The principle of prevention, therefore, is to cover this susceptible tissue at the proper time with a fungicidal coating that will prevent the fungus from entering and developing in it to form scabs.

Burger of the Florida Agricultural Experiment Station recommends spraying with 3-3-50 Bordeaux oil, 3 pounds copper sulfate, 3 pounds lime to 50 gallons of water (with additon of 1 per cent of oil) before the growth begins, and in severe cases another application about the time the petals fall. Schedules varying according to the severity of the disease have been recommended by Winston (1923) for commercial control of scab. These are as follows:

Schedule 1.—For orchards where Citrus scab is always serious, four applications are suggested:

First Application.—Just before growth sets in, use 3-3-50 Bordeaux mixture plus 1 per cent oil. This is to cover old scab lesions and to reduce very early Citrus-scab infections. Direct the spray especially toward the under surface of leaves.

Second Application.—In height of bloom, use 3-3-50 Bordeaux mixture plus one-half of 1 per cent oil. This is for the protection of expanding leaves and small fruit against Citrus scab.

Third Application.—Two weeks later, use 3-3-50 Bordeaux mixture plus one-half of 1 per cent oil. This is for the protection of small fruit against scab.

Fourth Application.—Two weeks after third application, use 3-3-50 Bordeaux mixture plus 1 per cent oil. If season is rainy, this is advisable for protection against scab. It will also reduce early melanose infection.

Schedule 2.—For orchards where Citrus scab varies from moderate to serious, the same schedule is suggested with the exception that commercial lime-sulfur solution, 1 to 40 gallons of water, is substituted for Bordeaux in the second and third spraying if the season is a normal one. If the season is unusually wet, the schedule recommended is the same as above.

Schedule 3.—For orchards where Citrus scab is of minor importance, three applications are suggested:

First Application.—Just before growth sets in, use lime sulfur, 1 to 30. This is to cover old scab lesions and to prevent early infections. Direct spray especially toward under surface of leaves.

Second Application.—In height of bloom, use lime sulfur, 1 to 40. This is to prevent infections on expanding leaves and small fruit.

Third Application.—Two weeks later, use lime sulfur, 1 to 40. This is to prevent infections on expanding leaves and small fruit. (Advisable only if season is especially favorable for scab development.)

Promising results at the Porto Rico Experiment Station with Bordeaux oil are also reported by Tower (1923), in a cooperative experiment in six orchards with 3000 trees of grapefruit. The trees blossomed in December, January and February. Four applications were given: Dec. 29, Jan. 27, Feb. 13 and Mar. 9, respectively. The results for the entire experiment were:

	Per Cent
Clean fruit	94.4
Trace of scab	5.2
Slightly scabby	0.4

In one orchard with sprayed and unsprayed trees, the sprayed trees gave 90.6 per cent clean fruit and the unsprayed trees 10 per cent. In another orchard, the trees sprayed four times showed 91.2 per cent clean fruit, those sprayed two times 83.9 per cent and those unsprayed only 24.5 per cent clean fruit.

Some modification as to detail of spraying will probably be necessary in each country where scab is found, in order to allow for differences in climate, seasons, commercial requirements and other conditions.

MELANOSE

Melanose is a raised superficial marking capable of producing serious injury to the quality of Citrus fruits, especially in certain parts of Florida

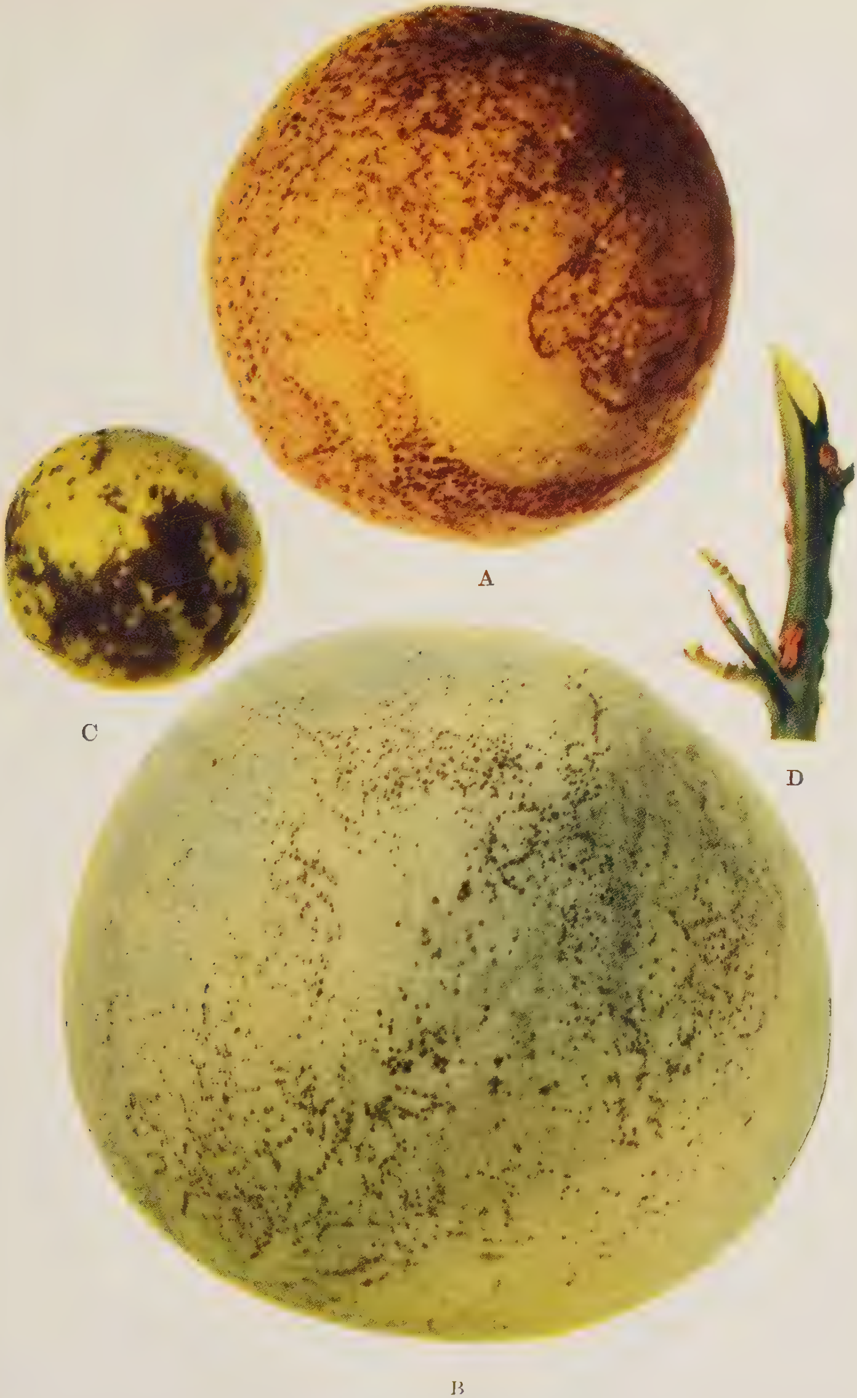

FIG. 188.—Melanose and exanthema. A, Melanose on orange fruit due to the fungus *Phomopsis citri;* as occurring in Florida. B, Melanose on grapefruit. C, Exanthema, a malnutrition disease on half-grown orange showing irregular surface markings consisting of glossy gum-soaked surface cells. D, Exanthema on twig showing raised excrescences in the bark. (*From Swingle and Webber* (1896)). (See also Figs. 91C and D.)

(*Facing page* 496)

and Australia. P. H. Rolfs, in a recent letter, reports it to be prevalent also in Brazil. It has been reported also in Mexico, West Indian islands, Algeria, Egypt, South Africa, Japan and China, but not as a serious disease. In some cases, its occurrence on leaves appears to have been confused with greasy spot or "black melanose." Melanose was shown by Stevens (1912) to be due to the fungus, *Phomopsis citri*, that causes Phomopsis stem-end rot (p. 401) and dying back of twigs (p. 228). A discussion of the characteristics of the fungus will be found in Chap. XVI under Fruit Rots.

Symptoms on the Fruit.—The disease develops on young fruits while they are enlarging. If the markings are numerous while the fruit is quite young and small, it is likely to be stunted and weakened. Under conditions adverse to the tree, this fruit may be the first to drop. If the fruit matures without being markedly stunted, its appearance is likely to render it either unsalable or to place it in a lower grade.

Melanose is distinguished on the fruit by small raised areas, dots or pustules of the same general character as those occurring on the leaves and twigs (Fig. 188). They are referred to by Floyd and Stevens (1912) as "raised areas of brown, gum-filled cells forming dots, lines, curves, rings and irregular-shaped spots" (Fig. 189). These individual dots or areas may vary in size from $\frac{1}{50}$ to $\frac{1}{25}$ inch (0.5 to 1 millimeter) in diameter. Around the margins and across the surface, lines of breakage may occur, giving an appearance suggesting dry, cracked mud. A flaky appearance may also develop, due to a slight peeling of the surface of fruit where the areas are crowded together, forming continuous crusts. The lesions or markings have a wax-like appearance, with various shades of yellow, brown or even black (roughly indicated by Ridgway's hazel, amber brown, Kaiser brown and burnt sienna). The individual dots may also suggest drops of partly burnt sugar with a dull instead of a glossy sheen. To the touch there is a surface roughness suggestive of coarse sandpaper. This aspect readily distinguishes it from smoother surface condition due to the markings of the rust mite. The melanose markings frequently occur in streaks following lines of gravity called "tear streaks" (Fig. 188). This is brought about by drops of water flowing down over the surface, leaving spores to germinate in their moistened tracks, during heavy dews or light rains.

Course of Development of Melanose.—The development of the melanose markings has been carefully studied by Floyd and Stevens (1912) and later by Burger (1923). In some manner, the fungus *Phomopsis citri* brings about an injury to the epidermal and subepidermal cells. A few cells are killed and become filled with a homogeneous, hard, gum-like substance which gives the color to the spots. It is unlike pure Citrus gum in being insoluble in water and, according to Floyd and Stevens, is probably a product of the protoplasm. They found that in early stages

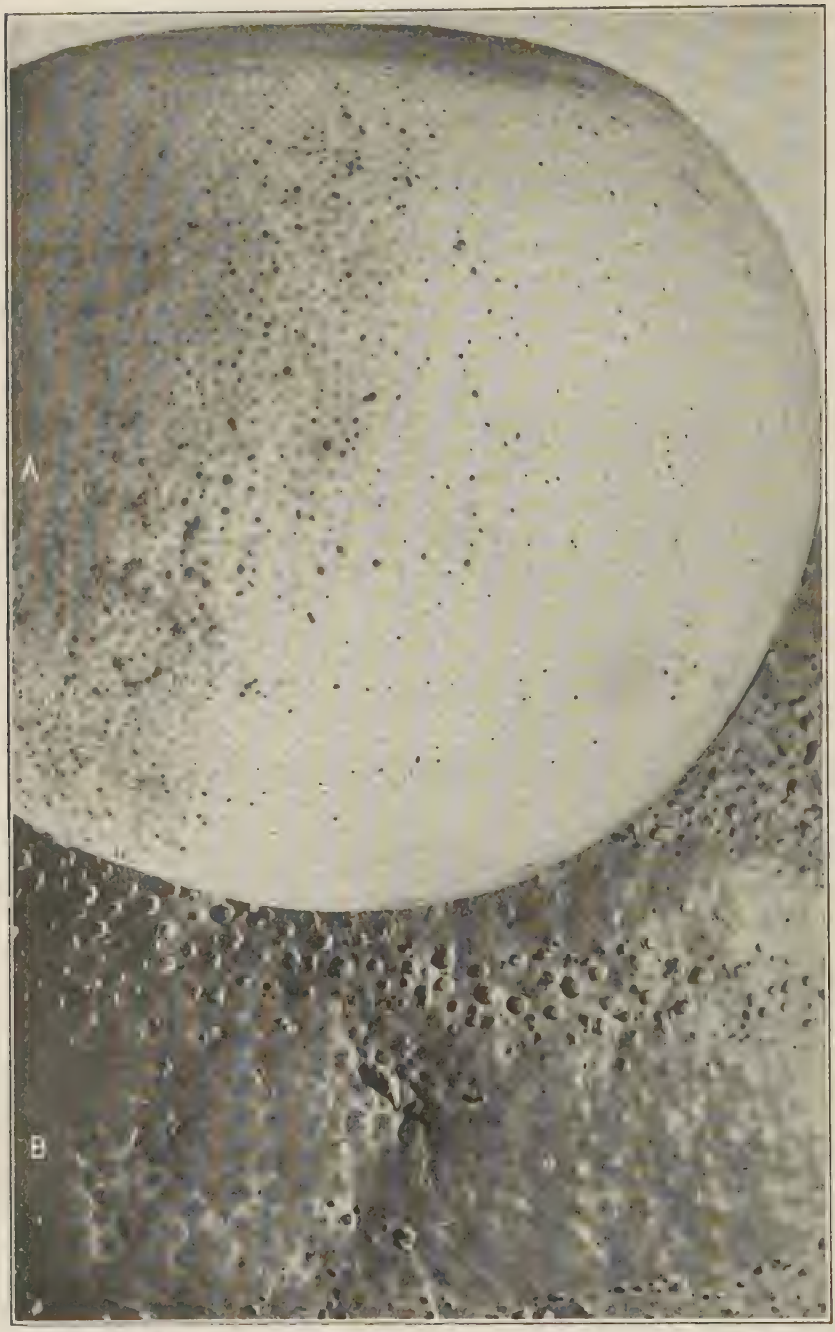

FIG. 189.—Melanose due to the fungus, *Phomopsis citri*, on grapefruit, Florida: A, natural size; B, magnified about three diameters. (A, *photo by C. O. Smith;* B, *after Floyd* (1911).)

the protoplasm is apparently in an active condition with the nucleus evident, but in later stages it is dead.

The shrinking of the cells produces a slight depression in the early stages, but in later stages the injured cells become raised by the development of corky tissue beneath (Fig. 189). The tissues involved in the markings are seldom more than five or six cell layers below the epidermis, and the direct injury, therefore, is confined to the epidermal and subepidermal tissues.

Control of Melanose.—Any control for melanose must take the line of preventing the infections of the fungus and the development of the markings, since there is no means of eliminating the markings after they have started to develop. Stevens found that the markings begin to the develop under Florida conditions in about three to seven days after spores are placed on young leaves. Burger showed that leaves and fruit four to six weeks old were immune to the disease even when subjected to abundant sources of infection in the laboratory. Fruit picked by him after the last of May were immune. Any preventive measures must, therefore, be carried out before that time, while the fruit and growth are young.

Prevention.—According to recent experience in Florida based on inoculation and spraying experiments, a thorough spraying of the fruit and leaves with Bordeaux-oil emulsion 3-3-50 plus 1 per cent of oil, ten to twenty days after the bloom has dropped, will materially prevent melanose injury to the fruit. One spraying ten to twenty days after two-thirds of the bloom has dropped is recommended by Burger, De Busk and Briggs (1923). Two sprayings are recommended by Winston and Bowman (1923*a*) as follows: first application, Apr. 1 to 10; second application, May 1 to 10. A suggestion is added that it may be possible to control melanose with a single application made immediately and quickly on the first indication of the disease on young fruit. This procedure, he points out, subjects one to a great risk of failure, if the attack comes on too rapidly at the outset, and is scarcely applicable to large orchards where immediate spraying of all trees is not possible.

Pruning out of all dead wood and twigs harboring the causal fungus has been shown by Stevens (1918*a*, *b*) to be beneficial in preventing a large amount of melanose, but this is not considered, in recent experiments by the Florida Experiment Station and the U. S. Department of Agriculture, to be commercially economical as a preventive treatment alone.

An interesting example of the benefit from commercial spraying for melanose in Florida is that reported by Burger (1923*c*), wherein 1255 acres were treated with 3-3-50 Bordeaux-oil emulsion in various groves of oranges and grapefruit from Mar. 2 to May 12. The average results for the entire experiment were as follows, in percentages of fruit:

TABLE 10.—RESULTS OF SPRAYING FOR MELANOSE ON 1255 ACRES

	Brights	Golden	Russets
Oranges sprayed	66.5	28.5	5
Oranges not sprayed	25.5	30.4	44.1
Grapefruit sprayed	69	24	7.0
Grapefruit not sprayed	24.6	33.3	42.1

The cost was 8 to 13 cents per tree, which, when figured as cost per box for the crop that year, was about 1½ to 2½ cents. The estimated profit from spraying was 56 to 61 cents per box on about 6000 boxes.

FLYSPECK FUNGUS

The flyspeck fungus, *Leptothyrium pomi*, derives its name from the black specks consisting of closely woven hyphæ of the fungus, about the size and color of a flyspeck, on the surface of the fruit (Fig. 190). These may or may not be accompanied by a sooty growth of fine hyphæ usually in blotches (not sooty mold), often called the sooty fungus or smoky fungus. The smoky-fungus blotches are produced by the presence of

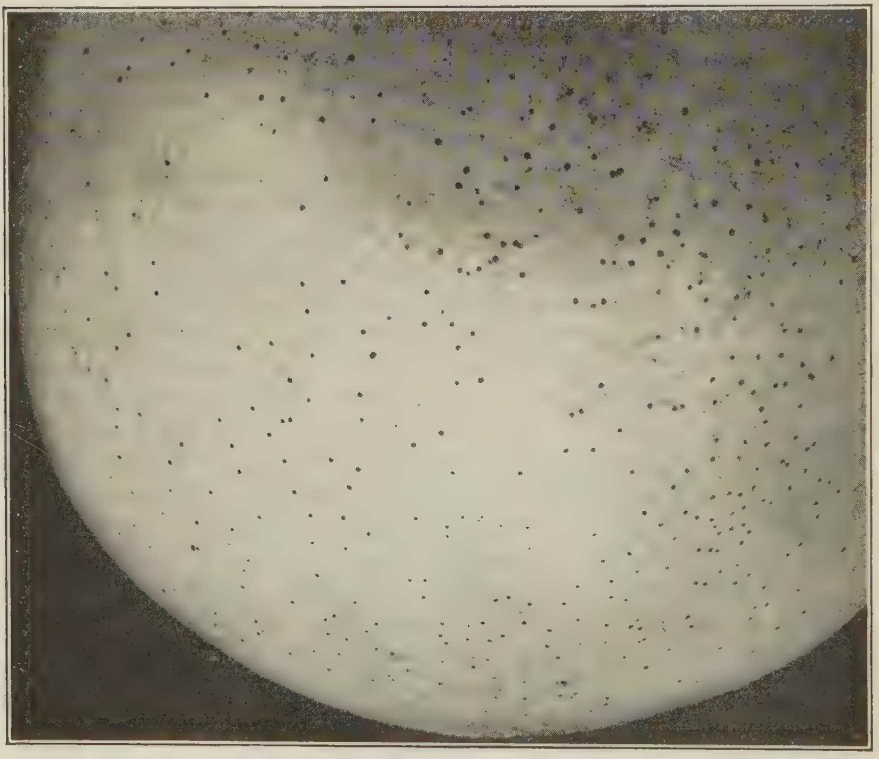

FIG. 190.—Fly speck fungus, Leptothyrium, on surface of grapefruit. About natural size.

minute light-brown fungal threads. No damage to the rind appears to result from the presence of this fungus, but the fruit is rendered unsightly and the grade is lowered.

Considerable shade and moisture appear to favor its occurrence. No spore stage has been observed on Citrus fruits, but on apples in Missouri sclerotia-like bodies form in November, which differentiate by the next March into pycnidia 25 to 100μ in diameter with hyaline elliptical spores 12 to 14 by 2 to 3μ (Duggar 1909).

EXANTHEMA

This disease, which is apparently the result of malnutrition, has attracted attention, especially in Florida, but is probably found more or less in all countries where Citrus is grown. The disease affects not only the fruit but the twigs and leaves and eventually the health of the entire tree (p. 243). Its effect on the fruit is often referred to by Florida growers as "dieback markings" and as "ammoniated fruit," the latter term arising from the supposed relation of its occurrence to the use of high percentage of "ammoniates," or nitrogen compounds, as fertilizers. (For details as to the history, distribution, cause, contributing conditions and control, see Chap. XI.)

Symptoms on the Fruit.—From a month old until nearly full sized, the rind shows brownish, glossy, gum-soaked areas affecting at first the superficial layers. These may result in vitreous-like hard layers on the surface (Figs. 91, 188). Sometimes the surface may show also small dots 1⁄50 to 1⁄25 inch (0.5 to 1 millimeter) in diameter which might, at first glance, be mistaken for melanose, but which are not broken at the edges. On oranges, the markings are varied in color, amber brown to reddish brown (amber brown to russet or chestnut to burnt sienna per Ridgway). On lemons in California, the color may be chestnut to mahogany red, burnt sienna or auburn. The markings occur most commonly on one side of the fruit. Small surface cracks may also occur over these areas, and frequently such fruit splits and drops. Drops of gum frequently form on these split fruits. Splitting and gum formation vary greatly with conditions. Gum may also form in the angles of the segments along the central axis or core (Fig. 191).

Primary symptoms on other parts of the tree are gum pockets at the leaf nodes, bark excrescences, stained terminal branches and multiple buds (Figs. 70, 71, 91). Secondary symptoms are frenching or mottle leaf, abnormal leaves, S-shaped branches and rosette or "staghorn" growth (see p. 244). Contributing conditions for the occurrence of exanthema are various and are discussed on page 249.

Control.—Prevention under Florida conditions varies according to circumstances, but consists in general in (1) avoiding any overfeeding with organic nitrogenous fertilizers, (2) avoiding too much cultivation, (3) mulching with heavy covering of grass, weeds or legumes, (4) keeping the soil well drained and (5) breaking up hardpan when present. Prevention under California conditions consists in carrying out (4) and (5) above and using good cultural and irrigation practices and sometimes additional bulky organic matter. It is possible that on sandy soils mulching with heavy covering of bulky organic material might also be beneficial.

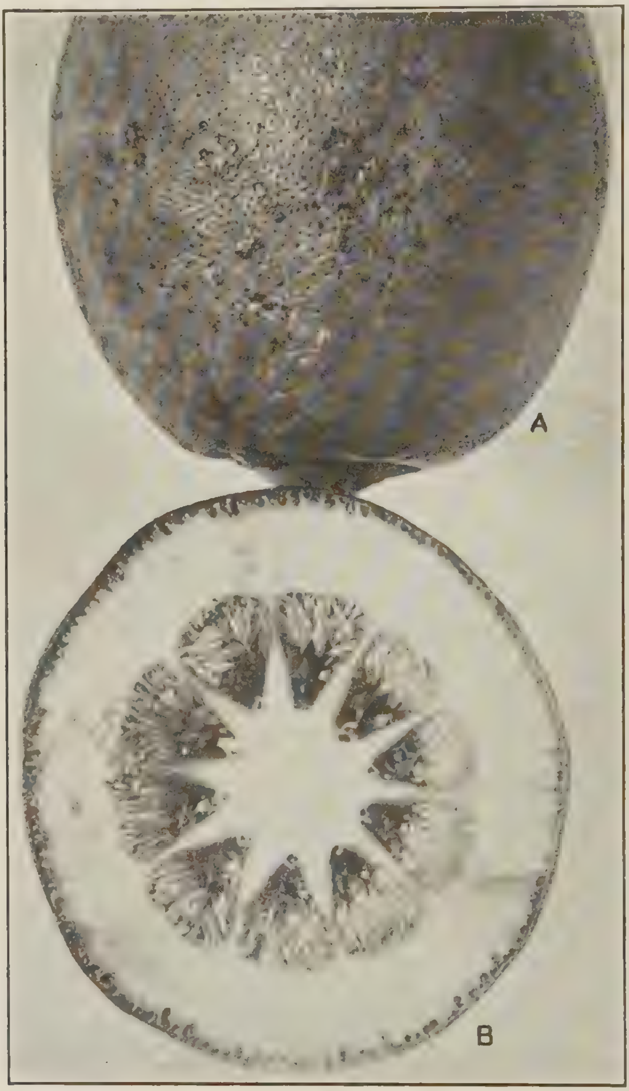

FIG. 191.—Exanthema on young fruits of orange showing: A, small superficial markings on the rind; B, gum formation at the angles of the divisions next to the central axis.

Treatment under Florida conditions also varies according to circumstances, but beneficial effects have been reported from the use of copper sulfate either spread on the soil or in the form of Bordeaux mixture sprayed on the trees at certain seasons (for details, see p. 250).

EXOBASIDIUM DISEASE OF MANDARIN ORANGES

A disease attacking young fruits of mandarin oranges has been reported by Siemaszko (1915) in the vicinity of Batum in southern Russia. The disease is described as producing a grayish-white, compact, cork-like formation on the surface of fruits. The young fruits appear as if covered with a coating of lime.

The cause of the disease is ascribed to a fungus, *Exobasidium citri* Siemaszko. The mycelium penetrates the tissue of young fruit. From its weft appear on the surface of the fruit the spore-bearing stalks (basidia) 24 to 32 by 5 to 6μ in size with two to six spores on their tips. These spores are hyaline and slightly narrowed at the ends of their attachment to the basidia and are, while attached, 5 by 2 to 2.5μ (Fig. 192). Occasionally, budding spores were found 7 to 11 by 3.5 to 4.5μ in size.

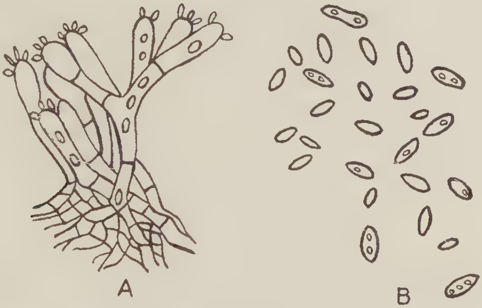

FIG. 192.—*Exobasidium citri:* A, basidia of fungus; B, spores, ×400. (*After Siemaszko* (1915).)

It is not reported how prevalent the disease may be nor are any control methods mentioned. We are indebted to M. Shapovalov for translation of the Russian description.

RUST-MITE INJURY TO FRUITS

(Russeting, Silvering and Buckskin)

One of the most common effects on the surface of Citrus fruits, especially in Florida and adjacent countries, is that due to a rust mite, *Phyllocoperus oleivorus* Ashm. The effects are usually known as russeting on oranges or silvering on lemons. Frequently, in Florida, the russeting takes the form of tear staining (Winston 1921) (p. 506). The so-called "buckskin" on grapefruit is also thought to be due to rust mites (Watson 1918).

Appearance of Rust-mite Injury. Russeting is a superficial effect on the surface which varies in color from gray, various shades of brown to nearly black. In August in Florida, the effect on large green oranges was found to be dresden brown, mummy brown or sepia in color (Ridgway 1912), with a smoothish surface crust when pronounced. The oranges take on, in many cases, a russet-brown color, giving rise to the term "russet orange." As mentioned previously, lemons may show a silvery condition of the surface (Fig. 193), giving rise to the term "silver mite"

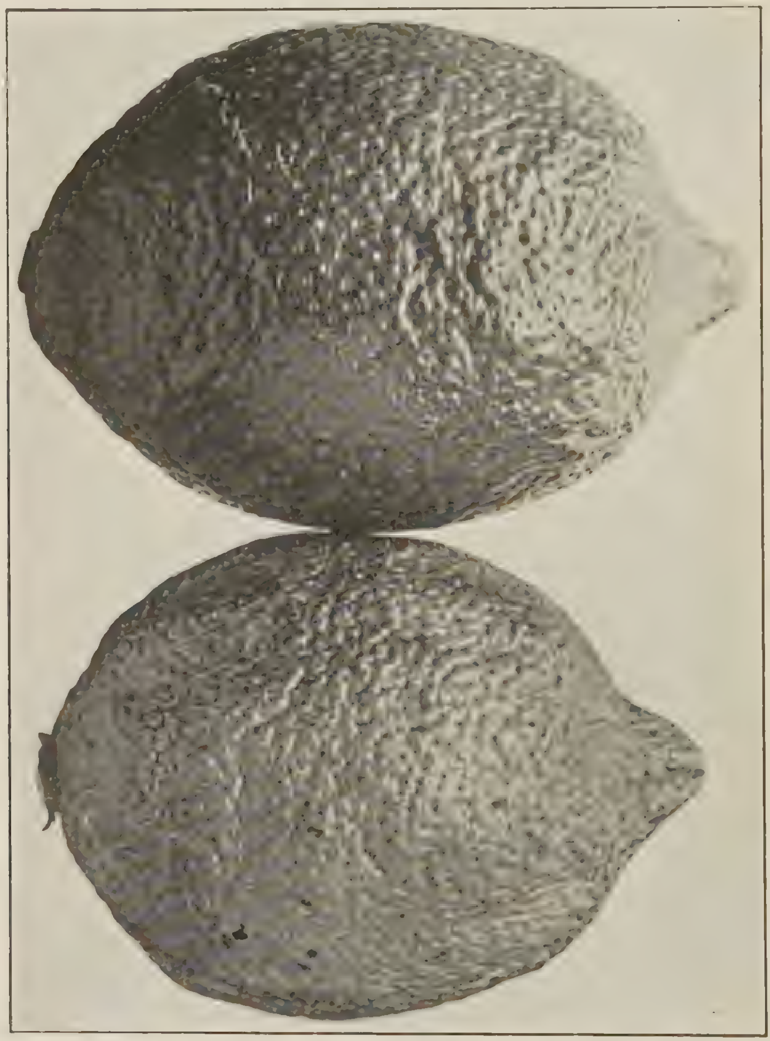

Fig. 193.—Lemon fruits showing effects known as "silvering" due to rust mite or silver mite. (*After Quayle* (1914).)

as well as "rust mite" for this same pest. Sometimes after the injury occurs, the rind may become tough and leathery, and the skin, as a rule, is thicker than normally.

On grapefruit and sometimes sweet oranges in Florida, rust-mite injury results in the development of a peculiar condition of the rind known by growers as buckskin or "sharkskin." The surface of the entire fruit resembles the pronounced effect of rust mite or silver mite and even thrips markings. Species of Alternaria and Cladosporium are commonly found under Florida conditions. The skin often becomes abnormally thick, which, together with a leathery, scurfy surface, has given rise to the above terms. Some of the fruits mature while still undersize. The fruit is rendered inferior and in many cases worthless because of the abnormal proportion of rind as compared to the pulp.

Contributing Conditions.—As a rule, the russeting effect occurs in Florida on the side of the fruit toward the light but usually not on the portion receiving full midday sunlight, but shades off gradually to the side of the fruit next to the tree. Fruits receiving a fair amount of reflected light may be evenly russeted, while those in the dense shade may not be attacked.

Moisture also has an important effect upon the rust mite. It has also been observed that they are much less prevalent in moist situations than on higher, dry localities. This may possibly be due to some parasitic microorganism which would naturally thrive better in moist situations (Speare and Yothers 1924). A very cold period is also fatal to the development of the rust mite.

Control.—The rust mite is best controlled by the use of sulfur compounds either by spraying or by dusting. A good form of dust is 3 parts of dry sulfur to 1 part of hydrated lime. It may be put on at night or in the early morning when dew is present. This dry sulfur is most effective if the weather is warm enough to liberate sulfur fumes. Spraying is also effective with lime sulfur (32°Bé.), 1 gallon to 50, or 1 gallon to 75 gallons of water. Under Florida conditions, a sulfur-oil emulsion spray may be used for rust mite, red spider, scale insects and white flies, all at the same time (Yothers 1918).

TEAR STAINING OF FRUITS

Tear staining or tear streaking of Citrus fruits may be brought about by several different causes or agencies, three of which are anthracnose tear stain, melanose tear streaking and rust-mite tear stain.

Anthracnose Tear Stain.—The anthracnose tear stain is usually a faint reddish to reddish-green stain, which is due to certain strains of the anthracnose fungus, *Colletotrichum glœosporioides*. It is probable, under certain conditions of moisture and temperature, that this stain may occur in any of the countries where the anthracnose fungus is prevalent. This is discussed more fully on page 454 (Fig. 165).

Melanose Tear Streaking.—A manifestation often known as tear streaking, which is usually much more pronounced than the above, is that of melanose, due to the fungus *Phomopsis citri*. Under Florida and Australian conditions, this melanose often occurs in the form of streaks where drops of water from the rain or dew have run down over the side of the fruit, resulting in infection along its track. These streaks are easily distinguished from the first-named tear stain by being composed of the projecting pustules of the melanose (Fig. 188).

Rust-mite Tear Stain.—The third form is a rather conspicuous stain running down in bands or streaks and often very pronounced under Florida conditions. This has been shown by Winston (1921) to be due to the effects of the rust mite. There is also some evidence in California that slight frost, followed by bright sunshine early in the morning on the south side of trees, is also the cause of a similar stain, the explanation probably being that oil is liberated from the rind and runs down over the side of the fruit. It may well be that a variety of agencies also causes the escape of small amounts of oil that in running down produce the same general type of spot.

Control.—The control of the first two forms, namely, anthracnose tear stain and melanose tear streaking, lies in spraying with a fungicide, such as lime sulfur or Bordeaux mixture. The control of the third form brought on by rust mite, of course, lies in the control of the rust mite itself, as was found by Winston. This mite can best be controlled under Florida conditions by the use of liquid lime sulfur or sulfur as a dust.

THRIPS INJURY

Injuries made by thrips on the surface of the skin when the fruit is quite young may result in a thin scurf that is sometimes mistaken for fungus injury. It has also been known as "silver scurf." There are several species of thrips that may produce scars or scurf of this nature on the surface of the fruit. In California, the most severe injury, not only to fruit but to foliage, is produced by *Sartothrips citri*. In Florida, a different species is responsible for thrips marks.

An effect resembling thrips injury in general appearance and known as "black scurf" has been attributed in Australia by McAlpine to a fungus, *Coniothecium scrabum* McAlp., and in South Africa by Putterill to *C. chomatosporum*. At one time in Florida, we were of the opinion that a similar effect known as scurf was probably due to a species of Coniothecium or Alternaria, but we now believe that this is thrips or other injury while the fruit is growing, followed by the growth of fungi which emphasize and discolor the scurfed areas (see Scurf under Wind Injury).

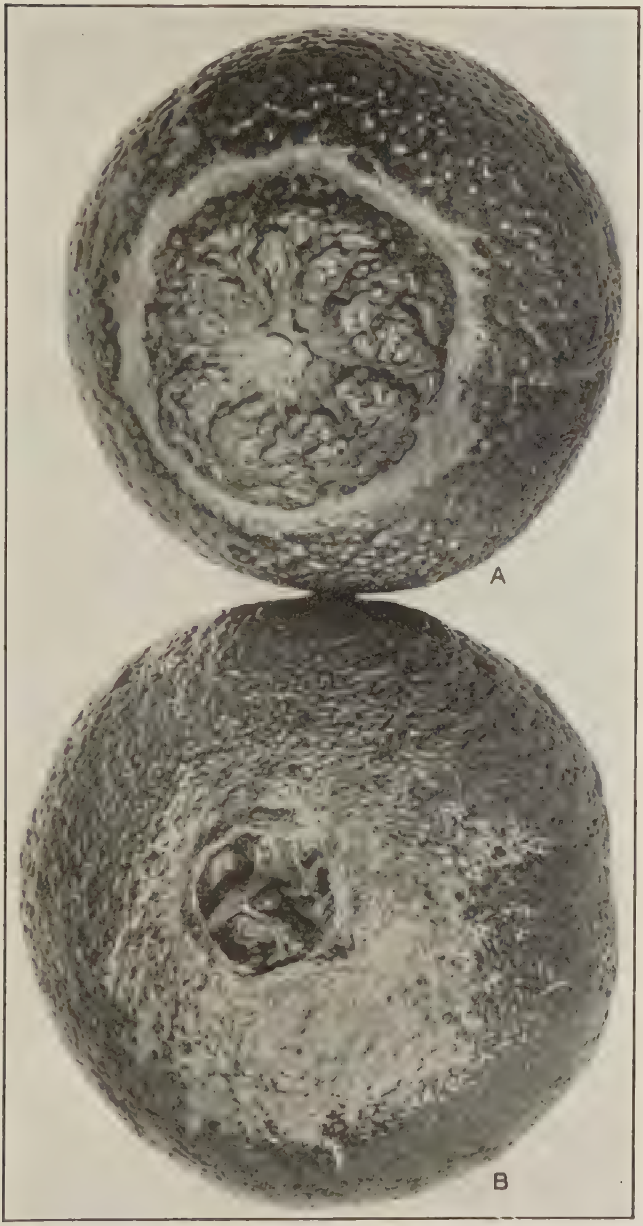

FIG. 194.—Thrips marks due to Citrus thrips. A, showing characteristic ring effect around the stem-end; B, showing more irregular area of scurf near the stylar-end. (*After Quayle.*)

In Italy, under the term "ruggine bianca," Briosi and Farneti (1904) have published certain illustrations having a partial resemblance to effects of thrips injury as it occurs in California and Florida. Briosi and Farneti found a fungus, *Rhynchodiplodia citri*, associated with it in all stages and report that they have reproduced a similar effect by inoculation.

Nature of Thrips Injury.—These small insects begin to feed on the surface cells of the ovary of the fruit after the petals fall. As the fruit enlarges, these shallow injuries result in a scabbing or "scurfing" of the surface. It may become silvery gray to brownish in color (Fig. 194). Under the lens, the epidermis will be seen to have broken up into irregular patches, which may be readily scraped off with the dull edge of a knife, leaving the fruit nearly uninjured. Fruit may sometimes be deeply grooved and distorted. It is similar to effects of rubbing or slight "wind chafing" occurring at certain ages of the fruit. Sometimes, the silvery, slightly scurfy appearance gives place to a rougher, darker, grayish scurf. It is probable that certain fungi play a secondary part in the appearance of the scurf.

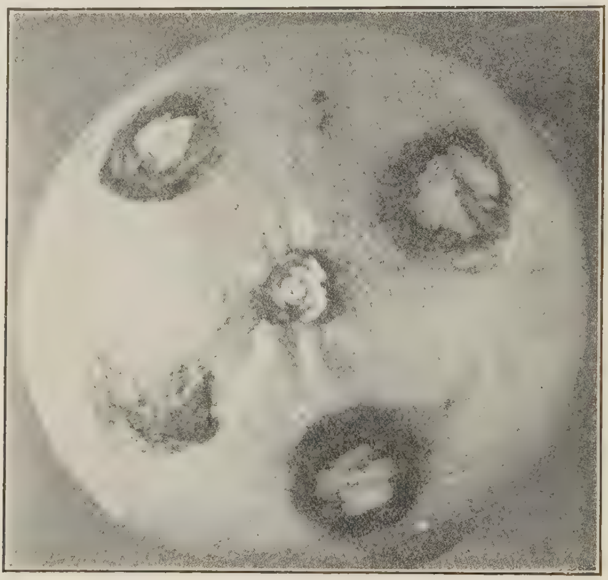

FIG. 195.—Markings on grapefruit due to the black thrips, *Heliothrips haemorrhoidales* at places where the fruit touched others in clusters, Cuba. (*After Earle and Rogers* (1915).)

Another type of thrips injury in Cuba is described by Earle and Rogers (1915) as due to the black thrips, *Heliothrips hæmorrhoidales*. Much injury was produced on grapefruits, *Citrus maxima*, when growing in clusters. The black thrips work on the older fruit at the areas where two fruits come in contact with each other, or where a leaf is in contact with the fruit. Discolored rings, gray in color, then dark brown and finally black, are produced (Fig. 195).

The usual remedy suggested for killing thrips is spraying with nicotine sulfate and lime sulfur. For black thrips on grapefruit in Cuba, Earle and Rogers suggest the possibility of thinning the fruit so that it will not hang in clusters.

WIND INJURY

A number of different kinds of effects may result from wind injury, some of which may easily be mistaken for the effects of fungus diseases, sometime after the injury has taken place. There are two general types of injury resulting from the wind: first, a dehydration and death of the cells by the removal of water from the fruit; and, second, mechanical injury to the fruit by whipping it about and knocking it against branches, thorns and other parts of the tree, or a combination of these two. In the first type of injury, the removal of moisture from the foliage and fruit by dry winds, more especially by winds that are both dry and hot, may be so rapid that the tree cannot supply water fast enough, and consequently, the tissues collapse. The leaves will also draw heavily on the fruit. Injuries to the surface cells of the rind also aid in hastening the removal of water.

Appearance of Wind Injury.—When the injury results from the actual drying out, the cells of the rind collapse and turn brown over a part or all of the fruit (Fig. 196C). Large sunken areas or wide furrows occur, becoming dark brown (Mars brown to mummy brown). The fruit frequently drops off or may remain on the tree, and the wound be partially repaired later. The injuries from drying out and rubbing often go hand in hand, the part of the fruit mechanically injured being the first to dry out. If a period of dry winds is followed by moist weather, certain species of fungi enter these wounds and often cause the rotting and decay of the fruit.

The lesions resulting from the fruit being whipped about and knocked and rubbed against the other parts of the tree vary considerably according to the age of the fruit and the weather conditions following (Figs. 196A, B).

Scurf.—On small green fruit, slight rubbing against other twigs or branches, may result in a thin scurf closely imitating thrips markings (Fig. 196A). A silvery or grayish thin scurf forms which may be easily scraped off, leaving an almost normal surface underneath. After such fruit has grown to normal size, the scurf may appear quite superficial. It may take on various shades, such as mineral gray, drab gray to smoky gray. It often appears as it if were a continuous membrane

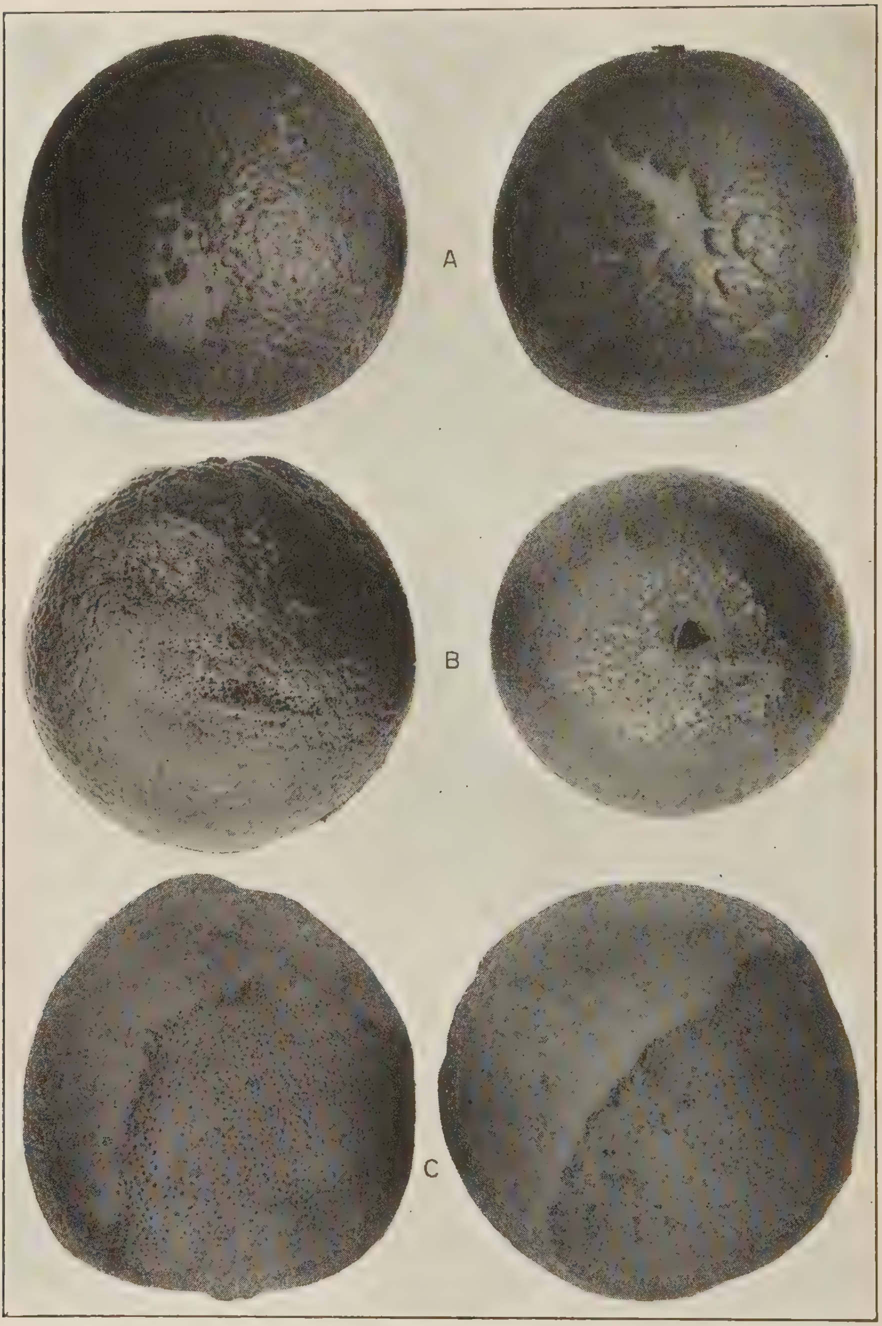

FIG. 196.—Types of wind injury: A, scurf resulting from injuries when the fruit was quite small; B, gray crusts and scabs resulting from rubbing against branches when fruit was nearly mature; C, drying out of the rind and sinking due to dry hot winds.

but with the hand lens is seen to be made up of very fine flakes or scales. On lemon fruits, the scurf is often accompanied by a production of extra tissues underneath, finally resulting in ridges or irregular raised portions in much the same way as that produced artificially and illustrated in Fig. 197. Extensive rubbing of green fruit against branches may result in larger, thicker scales forming scab-like areas (Fig. 196B).

This rubbing, due to winds at a time when the fruit is more nearly mature, if severe, may result in a still more deep-seated scurf, continuous and not easily scraped off, often of a pale drab gray. It may even affect the surface layers in such a way as to form a crust, and if moist weather follows, this gray crust may later turn dark or even black, due to the growth of fungi, such as Alternaria and Cladosporium.

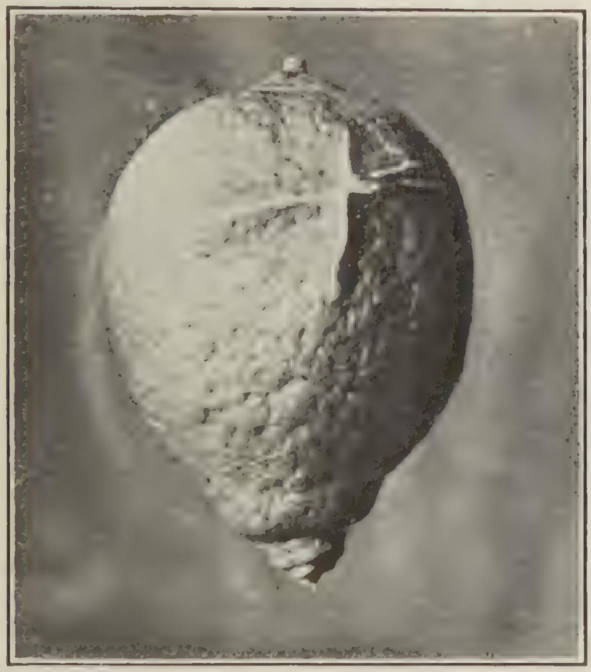

Fig. 197.—Lemon fruit which was scratched in the form of a small cross with a sterile needle when quite small, green, and rapidly growing in summer. Ridges of raised tissue were formed along the scratches as the fruit expanded.

Depressed Rubbed Areas.—Another type of injury on fruit that is ripe at the time of the wind occurs as elongated or depressed areas, where the surface of the skin is broken or rubbed off, liberating oil from the vesicles. This is usually a slight sunken area which in time turns drab to chestnut drab. Sometimes the surface of the rind is actually rubbed off as if it were sandpapered, leaving the oil cavities standing open and allowing the surface to become dry and gray. If the air is moist at the time of the wind whipping, there may be considerable injury from the action of the oil that is liberated from the oil vesicles. Beyond the actual mechanical injury to the tissue, the spreading of the oil produces an effect resulting in characteristic oil spots (see Fig. 171 in Oleocellosis). In dry sandy localities, the wind may blow fine particles of sand so constantly against the fruit that it wears off the surface cells on one side as if that side had been sandpapered. The same effect may be seen on the twigs and even on the trunk of young trees on the side towards the prevailing wind.

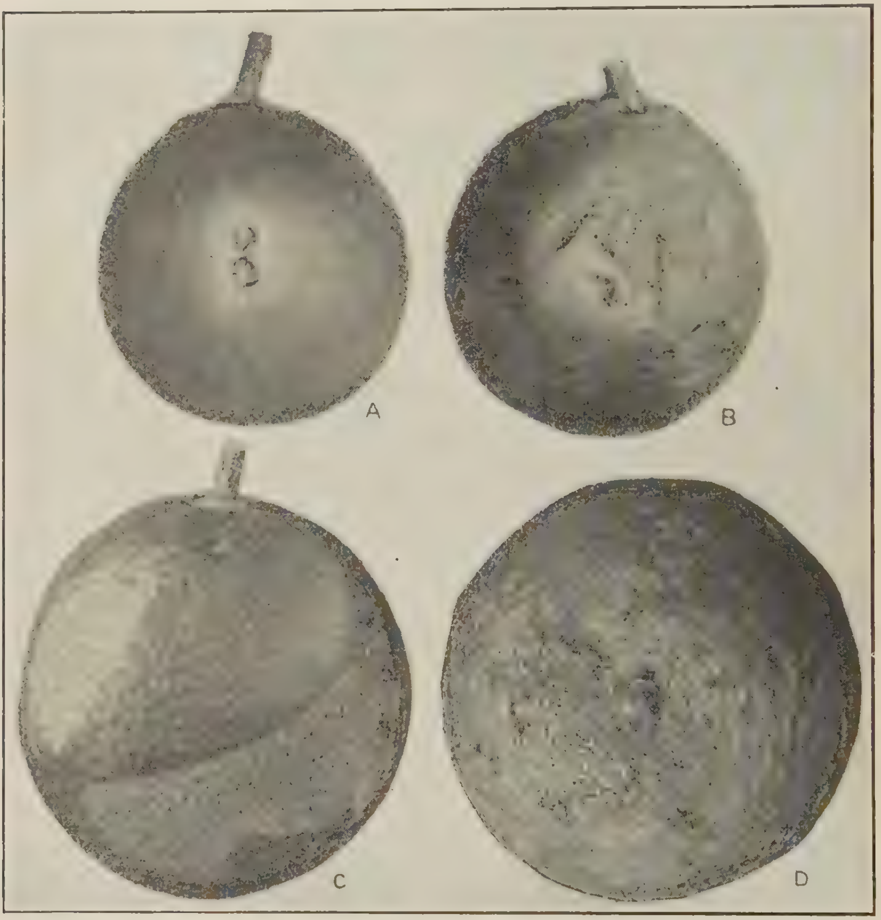

Fig. 198.—Types of spots produced by fumigating trees with hydrocyanic acid gas, as they appear not long after fumigation; A and B, half grown fruit with sunken spots having a yellow halo; C, mature fruit from tree fumigated in sunlight at high temperatures; the uninjured part was protected from sunlight; D, a more general spotting about the stem-end on mature fruit. (A, B and C, *after Woglum*, 1920); D, *California Experiment Station.*)

Prevention.—Part of the effects of wind injury may be reduced by care in keeping the trees in a healthy condition previous to the occurrence of the wind and having an ample supply of water in the soil for the trees to draw upon. Bulky organic matter in the soil may also improve its water-holding capacity and be a factor in lessening the drying out. Windbreaks may greatly reduce all forms of wind damage, if both the windbreaks and the trees have been supplied with sufficient water.

FUMIGATION INJURY

Many different types of injury may be produced on fruits by the effect of fumigation with hydrocyanic acid gas, a number of which are frequently mistaken for fungus diseases. One of the most common effects upon full-grown fruits is the pitting or spotting in which certain definite areas are killed, resulting in sunken dead spots of various sizes. In many cases fruit so spotted will drop from the tree, but in other cases a partial healing will take place, leaving various types of scab-like areas or spots resembling those produced by certain fungi (Figs. 198–200).

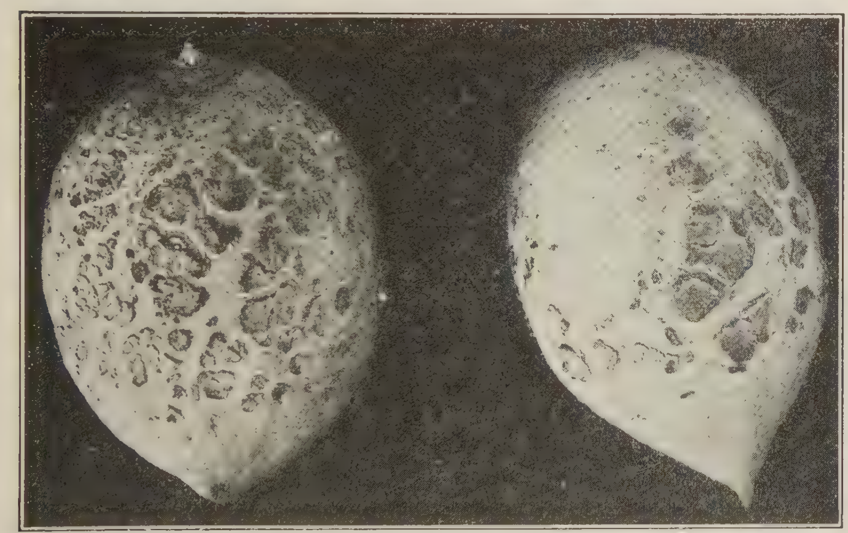

Fig. 199.—Dry surface scabs produced by fumigating young fruits with hydrocyanic acid gas as they appear many months afterwards. (*Photo contributed by J. E. Coit.*)

Orange fruits injured on the tree by fumigation in the autumn have been observed to have the following characteristics in the next April: The spots vary, some being quite superficial, with a layer of dry hard tissue which is slightly sunken in the center and has the Citrus-oil effect (oleocellosis p. 466) on the margins. The orange color surrounding the spots is less intense. Other more deep-seated spots halfway through the rind are buff brown to mummy brown (Prout's brown and mummy

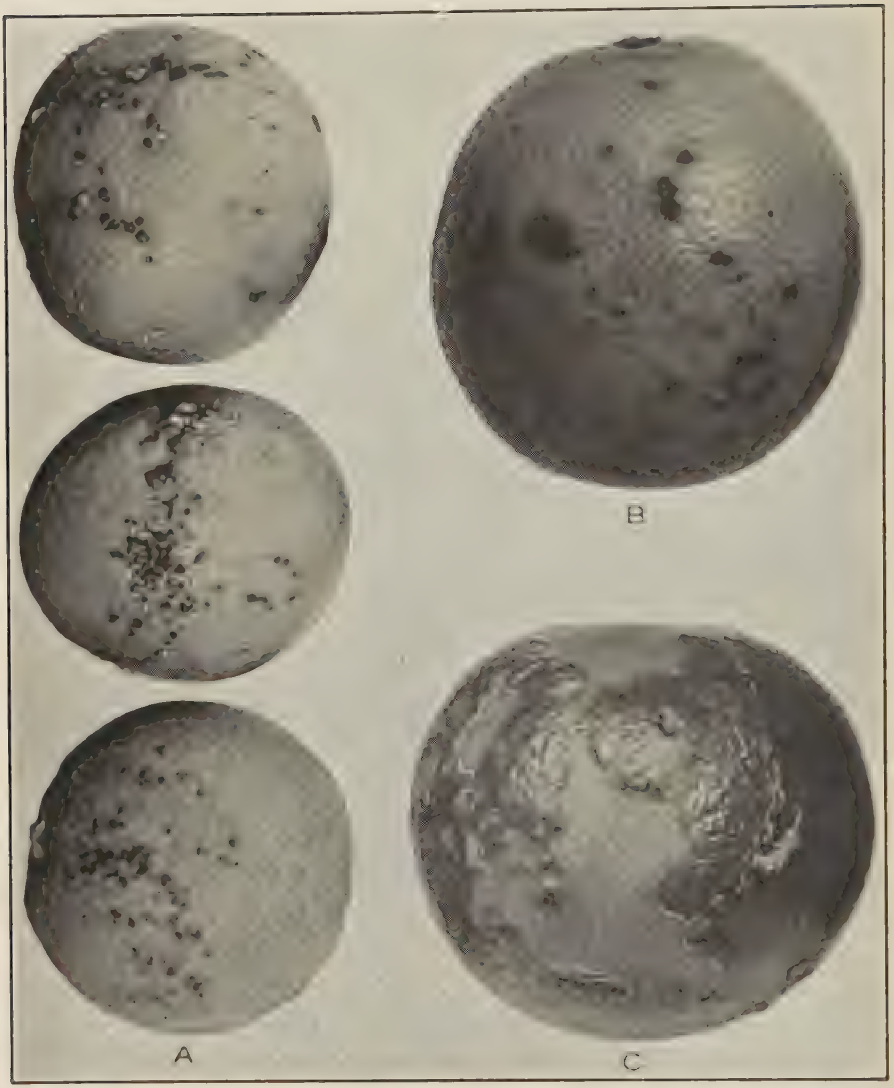

Fig. 200.—Some types of injury from fumigating trees with hydrocyanic acid gas as seen some months after fumigation: A, canker-like spots some of which could be easily mistaken for cancrosis or Citrus canker. These are sometimes produced especially on Valencia oranges in California if fruit is rather small, green and rapidly growing at time of fumigation. B, depressed spots with reddish brown hard tissue extending part way through the rind. C, gray or light drab-colored continuous hard layers of tissue drying and breaking away from the under portion of the rind over which a partially new outer rind has formed.

brown); others are sunken, cracked and scabby, extending one-fourth to one-half through the rind (Figs. 199, 200B, C).

When fruits are green or immature at the time of fumigation, a very severe burning or killing of part of the tissue may often take place without the fruit dropping. In such cases, it may become deformed, with the formation of irregular areas covered with scabs, which result from the healing of the tissue underneath (Fig. 200C).

One type of injury which occurs in fruit fumigated when it is small becomes a close imitation of spots produced by Citrus canker. The effect appears to result in definite, more or less circular spots in which a corky, spongy tissue is formed, sometimes accompanied by drops of gum (Fig. 200A). Just how such spots form is not understood. There appears to be a stimulation of tissue at certain points in the rind, resulting in cork-like raised spots. These have been noted a number of times on Valencia oranges in California on trees fumigated when the fruits were still green and only partly grown, not more than ¾ to 1 inch in diameter. The spots vary in size and character. Some are surface scabs 2 to 3 millimeters across and others more deep seated and raised, extending into the rind. Spots are gray to dark brown. Alternaria and Macrosporium hyphæ and spores are often found in them, accompanied by drops of gum. Such fumigation spots are more commonly found on outside fruits but may also occur less commonly on inside fruits. Spots of this kind, which have been definitely traced to fumigation in California, were so nearly like those produced by Citrus canker that even a canker expert was at first confused by them.

Severe spotting and shedding of fruit may sometimes take place if fumigation is preceded or immediately followed by spraying with Bordeaux mixture or other copper sprays (Fig. 86). There appears to be some combined toxic action between the gas and copper compounds, not understood.

SPRAY INJURY TO FRUITS

There are a number of types of spray injuries to the fruit that are often confused with spots due to ordinary diseases. The injury may consist (1) of deep burns or pits on the surface; (2) of death of the surface layers, which later form scabs or crusts as the fruit partially recovers; or (3) permanent superficial stains. The second and third forms are most commonly confused with definite diseases. An example of a hard crust or scabby surface resulting from burning with lime sulfur is furnished by Fig. 201. Certain oil sprays may, at times, produce a brown surface effect in the form of irregular spots resembling those on the leaves in Fig. 73. Oil-spray burning may also exhibit a brown, superficial staining somewhat similar to forms of russeting and tear staining. Under the hand lens, these stains may be made up of numerous dots so small and close together on the surface as to give to the unaided eye the effect of a continuous stain. Such effects are sometimes produced under certain conditions by Bordeaux mixtures or spraying solutions containing too high percentages of phenols. Some injuries are a combination of sunburning and spray injury. Frequently, the spray injuries may furnish dead tissue into which certain fungi may enter and produce rots or spots. At other times the effect of the spray may induce eruptions or pustules, as the stellate melanose produced by Bordeaux mixture (p. 228).

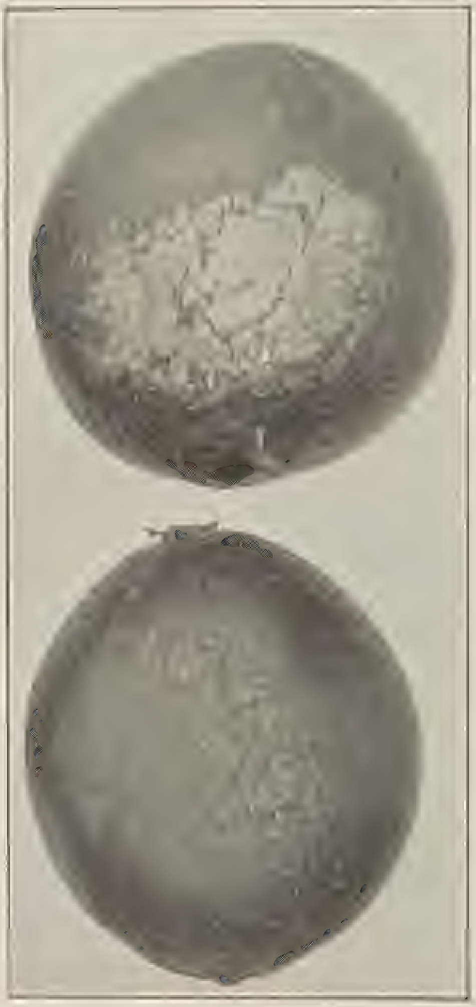

FIG. 201.—Spots produced by burning with lime sulfur spray. (*After Quayle* (1915).)

SPLITS

Openings in the rind, usually referred to by growers as "splits," are common in many varieties of Citrus, especially in the navel orange, and are sometimes associated with certain diseases.

Nature of Splits.—The most common form of "splits" takes place longitudinally along the same plane as the core. Such splits may either be on the side or start at the stylar end (Fig. 203). A less common form of splits is a transverse cracking or opening of the rind, usually at right angles to the core. This form is usually more ragged and irregular. Certain kinds of splits are thought to have some relation to the black rot fungus, *Alternaria citri* (Fig. 202). An infection by the Alternaria fungus will often be found near the navel orange in the place where the splitting begins. One or more fissures advance from the edge of the navel cavity. This type often begins before the fruit is half grown and the fruit opens up like a rose.

Another disease in connection with which splitting commonly occurs is exanthema. The surface of the rind becomes brownish, and the region occupied by the oil vesicles is impregnated with a hard, vitreous-like, gummy substance. Through these stained, brown areas, either shallow or deep fissures in the rind may occur. A more pronounced splitting may also occur in connection with the same disease in which rapidly growing fruits may split wide open. Exanthema also tends to induce gum internally at the angles near the core (Fig. 191). Other splits are associated with large protruding navels and with other irregularities in growth.

Theories as to Cause of Splits.—The factors involved in different types of splitting are very imperfectly understood. A few of the most plausible theories as to the contributing conditions that bring about pressures resulting in splitting will be mentioned here.

In the splitting associated with Alternaria, it is thought that the fungus may be instrumental in inducing an accumulation of pentosans or gummy substances in the region of infection, and that these substances then tend to absorb excessive water, resulting in a greater swelling at that particular point. Since it has been shown that the fungus *Alternaria citri* is capable of inducing gum formation (Fawcett 1923*a*), and that accumulation of gum often results in pressures sufficient to rupture the bark, it seems likely that such accumulation is a factor in fruit splitting. Any increase in pentosans, or gummy substances, also enormously increases the water-absorbing capacity of the tissues, so that they may swell so rapidly by absorption of water that the rind cannot withstand the added internal pressures.

Splitting accompanying exanthema may possibly have the same basis for explanation as the other, since accumulation of gum not only at the surface but also in the interior of the fruit is a common accompaniment in this malady.

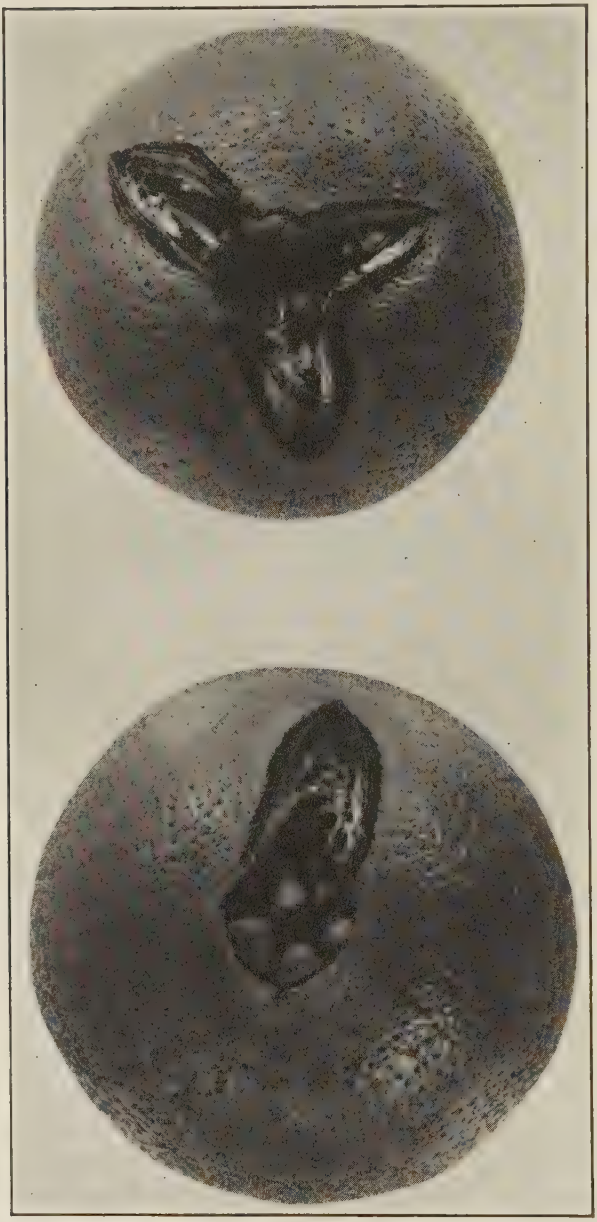

Fig. 202.—Splits on Navel oranges accompanying slight development of black rot due to *Alternaria citri.*

Irregularity of water supply is thought to produce a greater fluctuation in the interior than in the skin of the orange. Splitting under such conditions may also possibly be related to increase in pentosans and gums within the fruit. Prolonged dry hot periods with partial desiccation would tend to increase substances of this nature (MacDougal, Richards and Spoehr 1919). When a period of this kind is followed by moist, foggy weather or by rains, the presence of the pentosans would naturally cause the fruit to take up an excessive amount of water and thus cause a pressure within, which might result in splitting. The fissures will, of course, form at the points where the skin is weakest. This may occur at areas where the fruit has been slightly sunburned or where the skin is thinnest. It has been commonly noticed that certain varieties and even certain individual trees within the variety are much more resistant to this splitting than others. Coit has also observed that navel "splits" are confined almost entirely to fruits fully exposed on the outer twigs and especially at the top of the tree. Fruits with large protruding navels are also found in such parts of the tree due, he thinks, to the harsher conditions on the outside than on the inside. The larger this secondary or inner fruit, which is connected directly through the core with the stem, the more likely is it by growth to split the outer fruit.

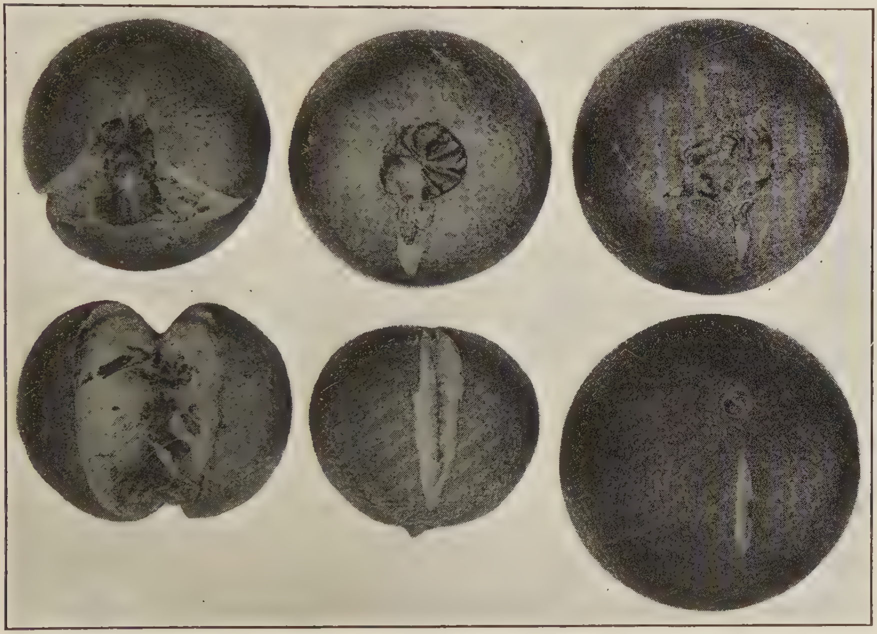

FIG. 203.—Different stages of splitting on Navel oranges. (*Photo by J. E. Coit.*)

Control.—Many of the contributing conditions to splitting, where they are due to changes in weather conditions, are, of course, largely beyond the grower's control. Where great irregularity in irrigation is a possible factor, this feature can be partially remedied by greater care in keeping adequate moisture in the soil in times of stress. As in case of June drop, suitable windbreaks and devices for keeping the air more humid in periods of very dry weather may help to avoid some of the splitting. Summer cover crops, where there is sufficient water supply for both the cover crop and the trees, might also be helpful. Coit suggests pruning in such a way as to encourage interior fruit, which seldom splits. When exanthema or other diseases are factors in splitting, the remedy is, of course, the avoidance of conditions, when possible, for the occurrence of these diseases (p. 249).

CREASING AND PUFFING

A condition usually occurring on very mature fruit and known as creasing or puffing is shown by irregular grooves running in various directions over the surface of the fruit, caused by the rind sinking. These may run both longitudinally and crosswise and produce irregular patterns. If the rind is removed, the inner spongy portion will be found to have pulled away just under these grooves, thus causing the outer skin to sink. Such fruits usually feel somewhat soft to the touch and are much more liable to attack from blue and green mold.

The cause of creasing is not understood. Some orchards are apparently much more subject to it than others. It is thought to be the effect of some climatic or soil conditions when the fruit is held for a long time on the trees after it has matured. Under the present condition of our knowledge of this trouble, no control method can be suggested.

MISCELLANEOUS SPOTS AND BLEMISHES

As Citrus fruits mature, spots of various kinds are frequently seen. Some of these develop while the fruit is still on the tree, while others develop after they are picked, in storage or on the way to market. The cause and manner of development of a number of varieties of spots have been ascertained, but the cause or causes for others are not known. Some of the more common of these, such as peteca, red blotch and brown spot, cold-storage spots, etc., have been discussed. Various other miscellaneous minor ones are frequently met with and await further investigation.

Difficulties that at once arise in determining the cause for some of these surface spots and blemishes are the facts that (1) diverse agencies may produce similar or identical physiological or pathological effects and that (2) the same agency may, under different conditions, produce different physiological and pathological effects. A striking illustration of the first case is found in the anthracnose spot, due to *Colletotrichum* *glœosporioides*, advancing from injuries on mature fruit. This spot cannot be readily distinguished from spots due to Alternaria and certain other fungi that advance from slight injuries. Black pit, due to a bacterial organism, and peteca, a physiological breakdown, are also similar. Diverse agencies may liberate oil from the oil vesicles of the rind, and the resulting spots, of course, will all be similar. On the other hand, many examples of the second case in which the same agency produces different effects might be given. The fungus *Phomopsis citri* is responsible for melanose, a surface effect on the rind of young, rapidly growing fruit, but will produce a radically different effect, a stem-end rot, on mature fruit. The anthracnose fungus will also produce diverse effects—a tear stain, a dry spot or a soft rot—apparently depending on climatic conditions, physiological conditions of fruit and the particular tissues involved. Other examples of both cases might be mentioned, but these are sufficient to show that the positive determination of the original cause of an old spot or rot on a fruit long after it is formed, is frequently difficult and often impossible without knowing the past history of the climatic conditions and the previous treatment of the fruit.

Inherited Brown Spots.—The tendency to form brown-colored spots in the tissues of the outer rind has been shown by Shamel, Pomeroy and Caryl (1924) to be transmitted by budding on certain variants of the Washington Navel and Thomson orange (Fig. 204A). These spots are similar to, though perhaps usually somewhat deeper than, the ordinary "brown spot" developing in storage or in transit.

Star-shaped Spot.—A small star-shaped spot (Fig. 204B) of minor importance has been noted in several localities in California. Nothing is known as to its cause. No organism has been found in the spots. It appears to be confined to certain trees in an orchard and does not spread from tree to tree. It is thought to be another case of inherited tendency, within the individual trees affected, to a certain weakness of the rind resulting in these star-shaped spots. The spot is very shallow, affecting only a few layers of cells, and $^1/_{16}$ to $^1/_8$ inch in diameter. As the fruits mature, the tissue next to spots may remain green longer than the other part of the rind. There is usually a very slightly depressed center. The effect somewhat suggestive of a star is emphasized when a slight drying of the rind takes place.

Slug Injury.—These are sunken irregular spots (Fig. 205A), usually on fruits hanging near the soil or in moist situations where high grass or weeds are growing under the trees. These white or gray sunken spots are due to tissue eaten away by slugs or snails. Sometimes spots much deeper but of the same general nature as those in Fig. 205A will be seen, due, it is thought, to snails.

Speckling.—Speckling of various sorts occurs on Citrus fruits, the specks or spots often being less than $^1/_{50}$ inch (0.5 millimeter) in diameter, sunken or not and varying in color. The cause for a number of these is not known and requires further investigation.

Speckling, thought to be due to the black-pit organism, has already been mentioned (p. 447). Very small, sunken spots of about the same size but red or brownish red instead of dark brown or black are frequently seen on lemon fruits in California and are thought to be due in part, but by no means always, to the anthracnose fungus. It is suspected that other fungi and agencies may produce a similar effect. Red pitting or speckling also frequently occurs on lemon fruits associated with the red blotch and sometimes appears to be an initial stage or form of red blotch. In some cases, what appears to the unaided eye to be a continuous stain or blotch is seen under the hand lens to break up into numerous very minute

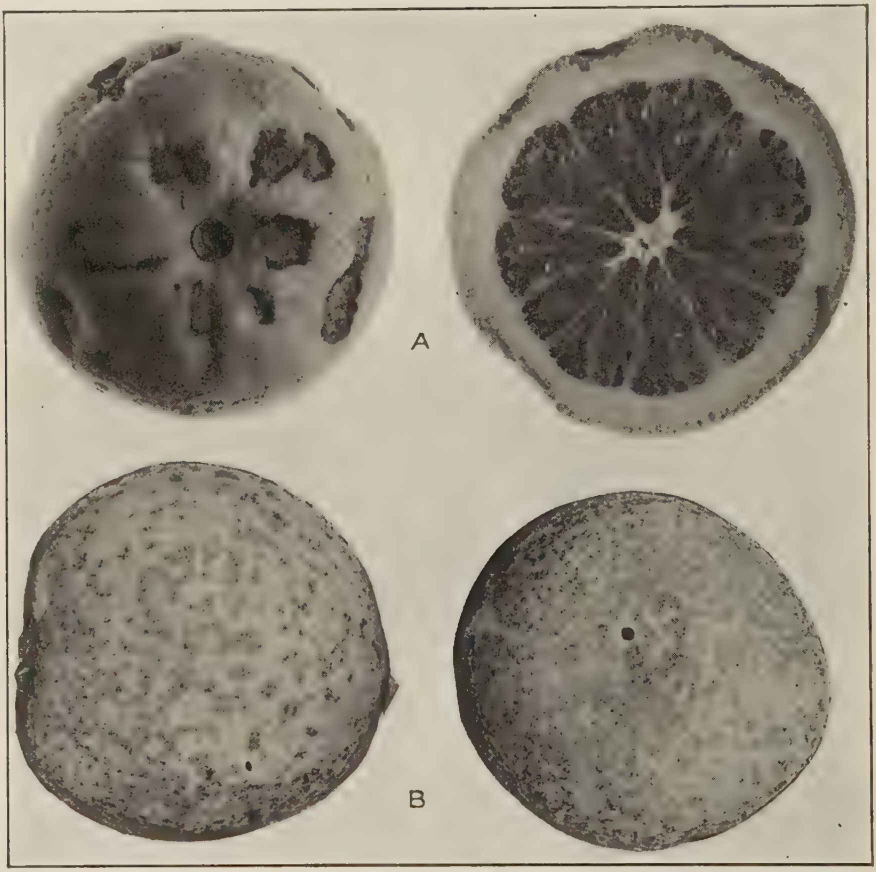

Fig. 204.—A, Thomson orange, with brownish spots thought to be due to inherent weakness of rind, a character transmitted by budding. B, Navel oranges with star-shaped spots thought to be due to some weakness of the rind inherent in the individual tree. (A, *after Shamel, Pomeroy and Caryl* (1924); B, *photo by C. O. Smith.*)

red or reddish-brown specks. Minute areas of tissue are stained and slightly sunken with small areas of normal tissue between.

Small black spots of unknown cause on grapefruit, mostly occurring as mere specks, have been reported by Matz in Porto Rico. They are generally circular and are situated in the rind of the fruit, sometimes very slightly sunken and surrounded by a darker green area.

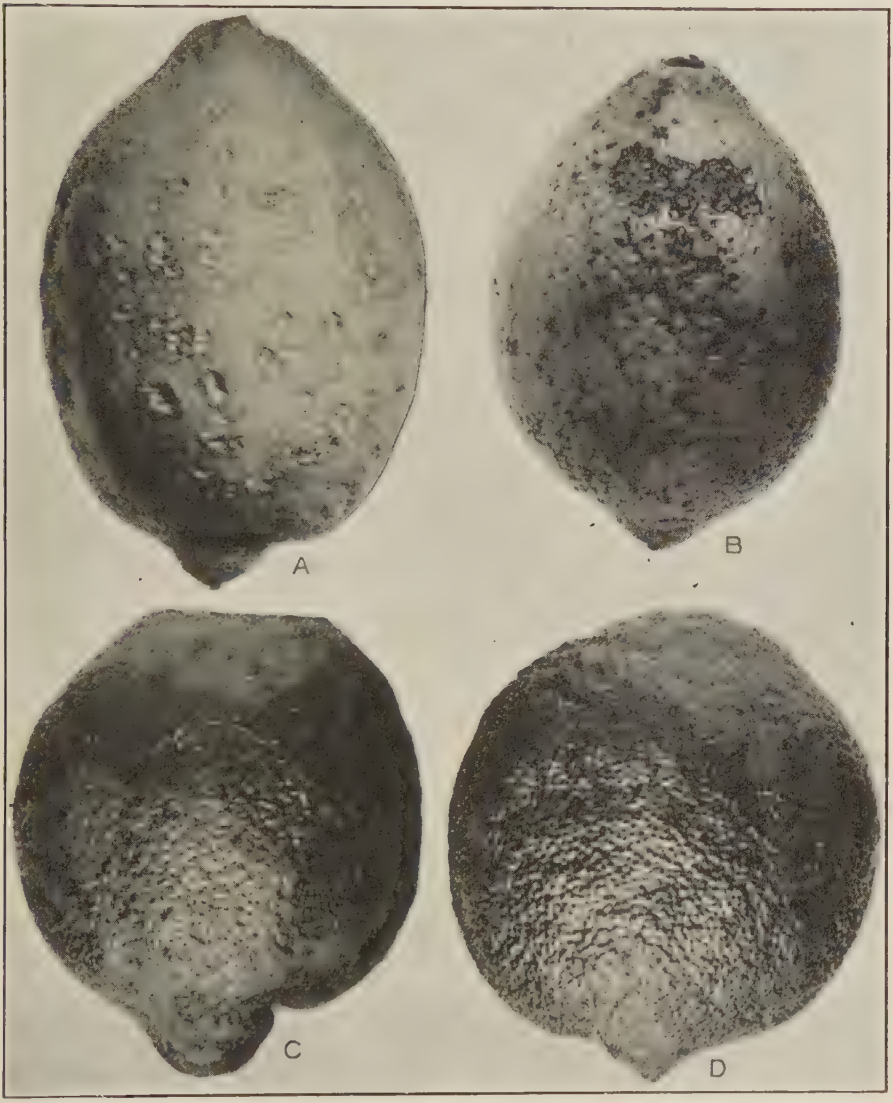

FIG. 205.—A, sunken areas on lemon eaten out by slugs; B, spots produced by copper sulphate which was allowed to become too strong in the washing tank. C and D, effect of scalding in washing tank with water at temperatures too high.

Chemical Burning.—Irregular pitting or sunken areas may occur on the rind from the effect of too strong concentration of certain chemical substances. That of Fig. 205B was the result of copper sulfate used at too high a concentration in the washing tank. Outer layers of cells were killed and the tissues sunken. Other chemical effects, as fumigation with hydrocyanic acid gas, will frequently produce similar pitting.

Heat.—Very high temperatures, either in the air and sunshine of the orchard or in the water of the washing tank at the packing house, may produce severe effects. Fruits scalded with too hot water show the oil cells standing out prominently, much as in the case of oil-spot injury. The surface of scalded oranges may take on orange or reddish-orange color when injured. When more severely injured, the tissue over the glands may be sunken or broken, and the oil may have disappeared. The fruits so injured dry out rapidly or, if in a moist atmosphere, soon decay with blue mold. Fruits on the side of the tree toward the sun often show sunburned areas where tissues have been killed, and shallow or deep spots have formed. The tissue in the sun may become many degrees higher than the surrounding air. Sunburning often accompanies or follows spraying, fumigation or frost, two or more factors being responsible for the injury. Spots of this kind furnish means for the entrance of various fungi, such as Colletotrichum, Cladosporium, Alternaria, etc. Water allowed to become too hot in washing will also produce severe spotting on fruit (Fig. 205C, D). The opposite extreme of temperature, such as frost injury, has already been discussed.

CHAPTER XIX

GENERAL PROBLEMS OF DETERIORATION AND DECAY OF CITRUS FRUIT

PROBLEMS OF DECAY AND DETERIORATION OF CITRUS FRUITS FROM THE TREE TO THE MARKET

Many problems arise in connection with decay of Citrus fruits during the various operations of handling the fruit from the time it is picked until it is finally placed on the market. These problems vary somewhat according to the climatic and economic conditions of the countries in which the fruit is grown, the transportation conditions, varieties of the fruit and location of the markets. The principles, however, are mainly the same wherever the fruits are grown but will be discussed with special reference to California and Florida conditions. The considerations as to detail may need modification when applied to conditions in other countries.

Conditions Influencing Decay.—Oranges and most other Citrus fruits, with the exception of lemons, the problems of which are discussed elsewhere (p. 529), are usually gathered under the larger commercial operations from a given set of trees at one picking. They are placed in field boxes and taken to the packing house, washed, dried, graded, sized, packed in boxes and loaded into cars or boats for shipment. Since most of the larger markets are long distances from points of production, the fruits may be a number of days or weeks in transit. They are then unloaded and sold at auction or direct to the jobbers or wholesale buyers, who, in turn, sell them direct or after some delay to the retailers.

In meeting the varied and complex problems in connection with decay, not only the factors favorable for the growth and infection of the invading organisms, fungus or other agencies must be considered, but also the physiological and other conditions of the fruit tissue itself, both external and internal. These factors may for convenience be considered under three heads:

1. The environmental effects while fruit is still on the tree.
2. The conditions in handling from the tree through the packing house to the car.
3. Transit, arrival and market conditions.

Environmental Effects.—Some of the factors operating while the fruit is on the tree are moisture, temperature, wind, frost, insect and other injuries, cultural conditions and age of the fruit.

Moisture stands as the key condition for the occurrence of such diseases as brown rot due to *Pythiacystis citrophthora*, determining whether or not the spores will develop on the surface of the soil and be splashed up and infect the low-hanging fruits. Moisture, as well as temperature in both air and soil, is important in determining whether weak or strong fruit will be produced and in determining whether certain decay-producing organisms will thrive. Wind, in effecting moisture and in producing injuries and scars from which decay afterwards may start, is also an important factor. Frost and extreme heat, both conditions of temperature, are, of course, contributing factors toward decay. These extremes may impair the resistance of the fruit, even when the tissue is not visibly affected. Insect injuries, such as those made by red spider, thrips, tortrix, scale insects, etc., produce conditions that may make the fruit more susceptible to decay. Mechanical injuries, such as thorn pricks, branch rubbing and injuries during the usual orchard operations, also contribute materially to rendering fruit susceptible to decay.

Another factor, by no means the least, and one that is closely connected with some of the conditions enumerated is the age of the fruit. The time taken for the fruit to come up to size, the time of storing in the packing house, the time consumed in transit, the time between arrival and consumption, etc. are all important in their relation to decay.

Picking in Relation to Decay.—In picking, the utmost care has been found necessary to avoid injuries of any kind to the rind of the fruit, as such injuries have an important bearing, especially on blue and green mold and on the oil spot due to Citrus oil liberated from the rind and to certain other spots and rots. The many ways that injuries result from picking are mentioned under Blue and Green Molds (p. 360).

When brown rot becomes especially prevalent, modified methods in picking the lower fruit separately are sometimes desirable, although this is more especially true of lemons (p. 531).

Another picking precaution used in very wet seasons is to avoid allowing the field boxes to stand for a long time on wet soil or during rains, as they are likely to become infected with various fruit-rotting fungi.

Washing in Relation to Decay.—When the fruit comes in from the orchard in a turgid condition, especially in a cool part of the year, and is to be washed in hot water, it is usually held for from one to three days before washing in order to avoid trouble from oil spotting or scalding. This matter is discussed more fully on page 532. Great care should be used in avoiding injuries from poorly constructed machinery or accumulation of stems or other obstacles during the process of washing.

Drying in Relation to Decay.—After oranges and most other Citrus fruits (except lemons) are passed through the washing machine, they are artificially dried as rapidly as possible by passing through a drying mechanism through which currents of rapidly moving air are passed.

This rapid drying is for the purpose of avoiding decay, which would be favored by the fruit being graded and packed in a moist condition.

Grading in Relation to Decay.—As the fruit comes out of the washing tank onto the belts, a careful culling out of all fruits with splits, wind scars, deformities, burns, spots and rots of all sorts, such as black rot and stem-end rot, will help to keep down decay. In order to avoid injuries from finger nails, the graders should wear gloves when handling the fruit.

Packing in Relation to Decay.—Fruits may be injured in pressing down the lids of packing boxes; the fruits near the ends and the middle may be so pressed as to break the skin. While it is necessary commercially to have full, closely packed boxes so as to prevent undue looseness on arrival, the packing should be done with such care that when the top is pressed down, the fruit is not injured. It is not unusual on opening boxes at the markets to see the green- and blue-mold decay most prevalent near the ends and middle of the top row. Special precautions for packing lemons are mentioned on page 536.

Transit Conditions Influencing Decay.—Probably the most important conditions influencing decay in transit have to do with temperature and ventilation. The lower the temperature, down to certain limits, the more will decay be retarded in development. If, however, temperatures of the fruit reach much below 40°F. for long periods, spotting and physiological derangement may result, which open up the way for decay later (p. 474). Temperatures of fruit in transit below 40°F. for short periods, however, and not below freezing are not likely to damage the fruit. The most favorable temperatures are those between about 42 and 50°F., and those between 50 and 60°F. are considered quite favorable for lemons. When the temperature of the fruit begins to climb to 70°F. and above, development of many kinds of decay becomes extremely rapid.

With fruit shipped in warm weather, it sometimes becomes desirable to cool it artificially by means of ice during transit or to precool it before shipping, or both. Icing of cars in transit from California in warm weather is not practiced so generally with lemons as with oranges, but is sometimes employed as a means of retarding decay. If the fruit is warm on starting, Powell (1908) found with oranges that iced cars usually covered about one-fourth their journey from California to New Yark before the average fruit temperature dropped to 50°F. When the fruit is not precooled, frequent icing is necessary during the journey to New York in warm summer weather. He found that the temperature of the fruit protected by the paper wrappers and packed tightly in the boxes, as is customary, lags considerably behind the air temperature. For this reason, the outside temperature may fluctuate rather widely within short intervals without such fluctuations in the fruit. Freezing temperatures outside, if not prolonged, may not be injurious to the fruit inside a packed car.

Precooling or icing merely retards, but does not ultimately stop, development of decay and should, therefore, not be a substitute for careful handling previous to shipment. This point is well emphasized by Stubenrauch, Ramsey and others (1914) as follows:

> Precooling may not safely be depended upon to offset decay following mechanical injuries due to improper methods of handling the fruit when preparing it for shipment, but it is a valuable and legitimate means of insuring arrival on the market in sound condition after each grower, packer and shipper has done his share in properly handling the fruit.

Decay on Arrival.—If the conditions, previously mentioned, in the orchard, packing house and transit are favorable for the development of decay, several varieties of rots and spots may be seen in the fruit when it arrives on the market. Although the blue and green mold are the varieties of decay most generally met with, other varieties may also develop. Other common forms of decay, especially with oranges, are the various kinds of stem-end rots, Alternaria rot, anthracnose spots, etc. At certain seasons, cottony rot, Botrytis rot, sour rot and even brown rot will be found, especially on lemon fruits.

Cold Storage in Relation to Decay.—Cold storage has not been used to any extent at the points of production of Citrus fruits, but is used to a considerable extent at times at the large centers of distribution and is being employed on shipments of Citrus fruits by boat from various countries where fruit carriers must experience hot weather in transit. The icing of cars in transit, previously mentioned under Transit Conditions, is related to cold storage in principle, though the storage period is usually short.

The general purposes of putting fruits in cold storage are to retard development of decay-producing fungi and to delay the ripening processes in order to retain the freshness of the fruit over considerable periods in warm weather (Powell 1908). The lower the temperature, until the freezing point of the fruit is reached, the more nearly will all fungus or bacterial development be stopped. Some few organisms, however, are capable of developing very slowly even at temperatures close to or at 32°F. (0°C.), as, for example, *Sclerotinia libertiana* and *Botrytis cinerea.*

From the standpoint of retarding the fungi, the lowest possible temperature without actually freezing the fruit would seem to be most desirable, but experience has indicated that certain physiological troubles arise at very low temperatures. A breakdown of the rind known as cold-storage spots or "pox" occurs (p. 474). Peteca and red blotch on lemons may also be emphasized. Internal breakdown, such as membranous stain of lemons, is frequent. The causes for these disturbances are not very fully understood, but probably have to do with interferences with the normal respiration processes and enzyme activities of the fruit under these conditions. The temperatures which, in general, have given the most trouble with spotting on Citrus fruits are between about 32 and 38°F. and under some conditions, even higher, to 40 or 42°F. For cold storage, Ramsey (1915) recommends a temperature considerably above 32°F. for all Citrus fruits, suggesting 38 to 40°F. for oranges, 42 for lemons and 45 to 50°F. for grapefruit. It was found by Hawkins and Magness (1920) in experiments with grapefruit that pitting and breakdown of the rind were considerable at 40°F. and lower, but were absent in ordinary storage. Later Hawkins (1921) showed that the pitting was largely controlled if the fruit was first held at 70°F. for from one to three weeks before going into cold storage. Adams (1923), after a number of experiments with Australian fruit, suggested that fruit be spread out on shelves for three to fourteen days after picking to remove some of the moisture from the rind, after which a temperature of 34°F. was recommended for long boat shipments from Australia to London. As a result of a series of experiments by Thomson (1922) with South African oranges, in which much spotting was experienced at low temperatures, a temperature between 43 to 48°F. or even 45 to 50°F. was recommended if fruit was kept for a long time in a ship hold in transit. Much cold-storage spotting was observed on Florida grapefruit five to twelve weeks in storage in July and August, 1924, in the eastern markets of the United States.

It seems advisable, therefore, in order to avoid the danger of serious physiological breakdown in most Citrus fruits, to hold them at temperatures rather higher than that most ideal for preventing all fungus decay. Some decay from fungus development is, in most cases, probably less injurious than general spotting and breakdown of the fruit from physiological derangement. It is possible to avoid pitting even at these low temperatures (in grapefruit, at least) by first holding them at 70°F. for one to three weeks before they are placed in cold storage, as has been shown by the experiments by Hawkins mentioned above. Forced ventilation, in which air currents are established while the fruit is in storage, is also a partial preventive for the spotting.

SPECIAL PROBLEMS OF DECAY AND DETERIORATION IN LEMON FRUITS

The handling of lemons[1] from the time they are picked till they are placed on the market differs in certain particulars and presents somewhat different problems from those that have to do with the handling of oranges and other commercial varieties and will, therefore, be discussed separately. The problems peculiar to the handling of lemons have caused the development of separate packing houses and, in many cases, separate associations managed by men who are especially trained and experi-

[1] We are indebted especially to H. J. Ramsey, H. W. Nixon and F. L. Williams for information in connection with certain of these problems in handling of lemon fruits.

enced for the work. The problems of decay and deterioration, especially in connection with storage, account for part of this difference. While some of the forms of decay and deterioration are the same in lemons as in other Citrus fruit, others are found to be quite different.

In order adequately to cover these problems of lemon decay, it is first necessary to mention the principal operations of handling lemons. Lemon fruits are picked, as a rule, when they come within a standard range of sizes. Lemon trees bloom and bear fruit during all seasons, not as one crop, as do most oranges. The lemon fruits must, therefore, be picked at frequent intervals, usually four to six weeks, and eight to ten pickings may be made in one year. The best lemon for the market is one picked when green and left for several weeks in the packing house to color. Since lemon fruits, however, color on the trees at different sizes, depending on the season and physiological condition of the tree, etc., the picked fruit as it comes from the orchard is usually made up of what is known as "dark green," "light green," "silver," and "yellow" or "tree ripe." In order to obtain the standard sizes, the fruit is usually picked by means of rings, the most common sizes used being $2\frac{6}{32}$, $2\frac{7}{32}$ and $2\frac{8}{32}$ inches in diameter and known as ring nos. 6, 7 and 8. The ring is held in the palm of the hand, and all fruits that will not pass through the ring are picked. The size of the ring employed varies with the locality, season and with the market demand.

Fruits usually have to be washed as they come into the packing house. This is done by dumping them into a tank of water, from which they are drawn past and between revolving brushes and out on moving belts. If the fruit is very dirty or smudged and hard to wash, the water is heated, and soap powders and kerosene emulsion are used in it. Hot water is also useful in preventing brown rot and other infection in the washer. When cold water is used, copper sulfate serves for this purpose.

As the fruit goes out of the washer onto a belt, it is picked off and segregated according to color; green, silver, tree ripe or yellow, and culls are put into separate boxes. Sometimes, a light-green and dark-green or "nigger-head" separation is also made. This is largely a keeping-quality separation, the keeping or storage quality decreasing from green to yellow.

The boxes of green, light-green and silver fruit are then put into a basement or into tents to color. The yellow or tree-ripe fruit may be packed as soon as it is dry. If time is not a factor, the coloring is allowed to go on naturally in the storage room, requiring about four to eight weeks or more, but if the market conditions require it, the fruit is colored in a few days by means of ethylene gas or by imperfectly burning kerosene-oil stoves. A relative humidity of 80 to 85 per cent and a temperature of 60 to 70°F. are usually employed. This forced curing is often known in California as "sweating."

After the fruit is properly colored, it is sorted from the boxes, usually onto trays, into market grades, generally known as "extra choice," "choice" and "standard," these receiving special "brand" names according to the association. Tree-ripe fruit or fruit of inferior keeping quality is often packed under a separate brand that does not bear the name of the association. In this process, the decayed and damaged fruit is eliminated. In some cases, grading belts instead of trays are now being used.

Each market grade is wrapped and packed separately and according to size, the two most common sizes being 300 and 360 in a box. Lemons are sized "by eye" as they are packed. The covers are then nailed down so that the fruit is very tight in the box to allow for shrinkage in transit, and the boxes are loaded, usually 348 to 406 boxes to a car.

The cars are sometimes iced if the weather is very warm, but usually go "under ventilation," and after about eight to twelve days arrive at their destination. During the coldest months, cars are often sent "vents closed to destination," to prevent freezing in transit. Representative samples of boxes are usually inspected for percentage of decay on arrival, and the carload is then ready either for private sale or for the auction market. If the latter, the decay may merely be estimated after it is unloaded at the auction display floor when samples are opened for inspection for buyers previous to sale by auction. After purchase, the wholesale buyer or jobber distributes it to his retail customers, either directly or after taking it to his own store. The wholesaler may or may not open and repack boxes, discarding decayed fruit. The fruit is either taken from the boxes by the retailer and displayed for sale or sold direct from the box with the wrappers left on.

Picking in Relation to Lemon Decay.—In picking, the utmost care is necessary to avoid mechanical injuries of any kind to the rind of the fruit, as these have an important influence, especially on blue and green mold and also on green spot, due to the oil liberated from the rind and to certain other minor spots and rots. The many ways in which picking injures the fruit are mentioned under Blue and Green Molds (p. 360). In many of the larger lemon growers' associations, inspectors are regularly employed to check up on each picker's work. The avoidance of four things that have to do with decay is especially stressed in picking: (1) clipper cuts, (2) long stems, (3) "green pulls" and (4) clipped buttons. Green pulls, or pulling off the green fruit without clipping, result either in leaving too long a stem or in pulling out the button and a piece of rind.

Picking should be avoided, if possible, while the trees are wet after heavy dews, rains or fogs. This practice will aid in eliminating the green spot that results from Citrus oil liberated from the oil glands (p. 466). When the weather is cool and the fruit wet, this volatile oil is not only more likely to be liberated, but is able to produce more marked effect than when the fruit is dry.

When brown rot becomes especially prevalent, modified methods in picking the lower fruit separately are sometimes desirable. Most of the infected fruit is within about 3 feet of the soil. If the fruit is being picked a few days after a hard rain in a bad brown-rot orchard, many fruits on the lower branches are likely to develop brown rot later in the storage room, and to contaminate the whole lot. In such cases, the fruit on the lower 3 feet may be picked separately from that growing above 3 feet, stored separately and inspected more often to eliminate the subsequent storage decay. Another picking precaution in very wet seasons in connection with brown rot, cottony rot and Botrytis rot is to avoid allowing the field boxes to stand for a long time on wet soil or during rains. Fruit remaining in boxes on the ground during a rain is especially likely to become contaminated with brown rot, and if a rank cover crop is present, cottony rot and Botrytis rot also appear. The empty boxes may become contaminated under the same conditions, and the fungus spores or mycelium infect the fruit placed therein.

Time and frequency of picking lemons may also have an important bearing on diseases, such as internal decline and Alternaria rot. If the season is such that these diseases are likely to be present, extra close picking of fruit so as to get the fruit off before it has time to deteriorate sufficiently to show marked symptoms of internal decline will help to avoid trouble on the market. As has been mentioned on page 391, the Alternaria rot is aided by a physiological breakdown or weakness and age of the fruit. It is courting trouble from decay to hold back such fruit on the tree. If fruit tends to color up undersized, it should be promptly picked in order to avoid future trouble. Some growers use a smaller ring so as to keep down the "tree ripes" under internal-decline conditions. The same precautions are applicable to most of the stem-end rots and other decay that occur mostly on weak or overmature fruit. Care in loading and hauling fruit after picking has been discussed (p. 360).

Washing and Segregation of Lemons in Relation to Decay.—When the fruit comes from the orchard green and turgid, as in the cool part of the year, and is to be washed in hot water, as is now the common practice, it should remain standing from one to three days in order to avoid trouble from oil spotting or scalding. If green fruit direct from the tree is put into hot water at 115 to 120°F., a smell of oil will be detected, which is a warning that green spot is likely to be severe in storage, but if the same fruit is allowed to stand (even though not perceptibly wilted), the oil will not then be liberated at this temperature. The purpose of the hot water is to aid not only in cleaning the fruit but in preventing the infection and spread of brown rot and other fungi. It has been found by experiment (Fawcett 1922*a*) that brown rot spores are killed and infection is prevented by water at 115°F. (46.1°C.) for two minutes or at 120°F. (48.9°C.) for one minute. It has usually been found that 115 to 120°F.

is as high as it is safe to use water in washing lemons. If cold water is used and prevention against brown rot is desired, copper sulfate at the rate of 1½ pounds to 1000 gallons is used (Smith, Ramsey *et al.* 1907). Some packing houses have a separate tank of copper sulfate through which the fruits go after they have had the hot-water and soap treatment. Some packing houses, in order to clean fruit more perfectly, even put it through two washing machines set in tandem and known as "tandem washers" and in addition, through a third tank of copper sulfate.

The washing tank, with an extension through which the fruit floats before going past the brushes, may also be employed to pick out bad cases of internal decline on tree-ripe fruit, by observing the manner in which the fruit floats with the light stylar end pointing upward. Badly frosted fruit may also be picked out from such a floating tank at the time of washing. Water-gravity separators, worked on the principle that frozen fruits bob up faster than sound fruit after dumping into running water, are also employed by some for the same purpose. Further injuries to the fruit at the brushers and other parts of the machinery should also be carefully avoided. A supplementary treatment at the time of washing is the use of borax or other disinfectant in a separate soaking tank (see p. 361).

As the fruit comes out of the washing tank on to the belts, a careful culling out of all fruits with splits, "wind scars," burns, spots of black pit, anthracnose, brown rot or other serious defects is done to prevent decay in storage. This is also a place where certain phases of internal decline on green, light-green or silver fruit may be picked out by watching for the symptoms of "off color" at the stylar end. In order that injuries from finger nails be avoided, the sorters wear gloves in handling the fruit.

Curing Lemons in Relation to Decay.—During the natural coloring process in the basement or tent, certain kinds of spots and decay may develop. It is here that "green spot" from liberation of oil becomes evident. Brown rot, if prevalent, will begin to show itself in four days to a week and may do damage by contact with sound fruits. Cottony rot and Botrytis rot may also begin to spread by contact in such fruit. Badly injured fruit will begin to develop "blue-contact" and "common green" mold, the former having some tendency to spread a little by contact. Alternaria rot and some of the stem-end rots may begin to develop in weak fruit or fruit weakened by internal decline. Some physiological breakdown may also begin to develop, such as peteca, membranous stain and red blotch, in fruit picked in the cooler parts of the year. Rise in temperature will speed up most of the rots, and humidity will have an influence on a number of them, especially on blue and green molds. Lack of ventilation is also thought to have an important influence in increasing red blotch, membranous stain and possibly peteca.

Forced Curing or "Sweating" of Lemons in Relation to Decay.—Sometimes the market demands are such as to make it desirable to hasten the natural process of curing, a practice known in California as forced curing or "sweating." This was formerly done by means of gaseous products from kerosene stoves. Recently, Denney (1924*a*, *b*) has found that ethylene gas in very small quantities, 1 part in 10,000 to 1 part in 1,000,000, was capable of producing the same results. He found, however, that a very high percentage of gas (80 per cent, for example) delayed coloring. Coloring was also delayed by as high a temperature as 92°F. and by as low a temperature as 45°F. In practice, a temperature of 60 to 70°F. with a humidity of about 80 per cent is considered favorable. Under favorable conditions, fruit is thus colored in five to ten days.

Denney found that forced curing is accompanied by greatly increased respiration. The life processes are stimulated, and usually an abscission layer is formed that results in the loss of the "buttons." It has been found that certain forms of physiological breakdowns are greatly aggravated by forced curing, more especially the red blotch and to some extent membranous stain. If the gas is too strong, it may weaken the tissue and open up the way for blue and green mold, the stem-end rots and other forms of decay depending on weakened tissue. This, however, is largely prevented by keeping the gas sufficiently dilute. In practice, the maximum strength, even in tents, is usually about 1 cubic foot of gas to one car space of about 5000 cubic feet.

Storage of Lemons and Decay.—Under certain conditions of the market, lemon fruit is stored in the packing houses in California for a much longer time than is necessary for it to color, sometimes three to four months, but rarely longer. This gives time for the appearance of a number of additional kinds of breakdown and decay that require longer periods for their development or that depend upon age and weakness of the fruit. The life processes, active and strong in freshly picked fruit, become weaker and less active with age, and the resistance to many kinds of decay is decreased. The varieties of decay mentioned in the last paragraph may increase in amount by contact or further development, and new sorts may appear. In fruit long in storage, especially in summer, sour rot, a soft, watery decay, may be troublesome; blue and green mold continue to develop, and the Alternaria or center rot slowly increases and in some seasons may become the predominating type of decay; the pliable, leathery stem-end rots due to Phomopsis, Diplodia, Dothiorella and Pleospora begin to be evident; softer stem-end rots due to Colletotrichum, Fusarium and Alternaria also make their appearance, though usually less important.

In decay and deterioration of stored fruit, the various factors of temperature, humidity and ventilation have been found to be important. Basement storage is largely used in California. The model basement usually consists of one large room directly under the packing house. About three-quarters of its height is below the surface, the upper quarter being furnished with numerous doors or windows that may be opened for ventilation. It should be 12 feet high from floor to joists, with isles of solid concrete and runways for stacks of fruit. The fruit is stored loose in packing cases, piled in stacks of nine or more. The stacks are placed about 2 inches apart and the rows of stacks 8 inches or more apart. The upper boxes are covered, and the outside or end stacks are often papered to prevent wilting. A temperature between 50 and 60°F. is considered most advantageous. It may be as low as 50 to 55°F. during the winter months and gradually increases to 60 or 65°F. during the spring and rarely to as high as 70 to 75°F. in the warmest months in some sections. The rise of temperature up to a certain point has a great accelerating influence on the rate of growth and development of most fungi. Roughly speaking, the rate of growth in the ordinary ranges of temperature for storage is about doubled for every rise of 18°F. (10°C.); *i.e.*, brown-rot fungus will develop about twice as fast at 78°F. as it will at 60°F. It is seen, therefore, that keeping the temperature down to a certain limit is a very important consideration in storage (see Cold Storage, p. 528). A relative humidity of about 80 to 85 per cent is considered most advantageous. Ventilation is usually obtained by opening all the outside doors. The temperature is kept down in warmer weather by closing the doors in the daytime only. In some cases, forced ventilation is practiced.

Grading Lemons Out of Storage in Relation to Decay.—As each lot of lemons comes out of storage to the grading table, it is carefully judged as to quality and appearance, and a decision must be made accordingly as to how it shall be graded. This perhaps is the most critical phase of the whole process of handling. Success or failure with the fruit on the market often depends on decisions made at the grading table.

Fruits which have developed decay and deterioration are here removed. Certain samples of fruits are also cut to determine their internal condition. In removing the rotted fruit, gloves are discarded, so that they will not become contaminated with spores. A stick with a projecting nail is often used to take the worst rots out without touching them with the hands. Dry visible spores of green mold on sound fruit in contact with fruit that is decayed are usually wiped off with cotton waste or rags. Wet spores of any kind, however, are usually sufficient to condemn a fruit as a "contact." As a general rule, any decay in fruits close together or in a cluster is known as contact rot, and all fruits touching this cluster are designated as contacts. Any fruits touching a single rotted fruit, however, are not considered to be contacts. The contacts are either discarded as culls or are set aside to determine whether they will develop decay later.

The most difficult problems in grading arise in connection with internal maladies or effects that are not so readily detected on the surface;

frost effects, membranous stain, internal decline and the center-rot form of Alternaria decay. If on cutting a lot of fruit a large per cent of these effects is noted, this lot is graded with great care to eliminate, as far as possible, all undesirable fruits. Usually none of such lots are allowed to be packed in the best grades.

The separation of beginning stages of Alternaria rot is especially difficult. It is being done, however, in a very rough way in some cases by such indefinite signs as "high color," "black button," "button off," "black at scar" and "soft fruit," but some more definite, satisfactory method still remains to be evolved. Blemishes of various sorts that have not already been thrown into the culls during segregation at the washer are eliminated in grading. Among the various blemishes may be listed wind scars, thorn punctures, scale insects, sooty mold, thrips marks, tortrix punctures, peteca, anthracnose and other spots, red blotch, black pit, hail marks, frost marks, sunburning, fumigation injuries and deformities. Among deformities are coarseness, pebbly skin, long necks, long noses, tomato shapes, etc.

Packing Lemons in Relation to Decay.—The effect of lack of care in packing has already been mentioned in connection with the prevention of blue and green mold. Whether or not lemon fruits will be injured so as to lead to decay on pressing down the lids depends to a great extent on how they have been packed. The stem end of the lemon should face the middle partitions and ends of the box to avoid injury to "nipple" or stylar projection. The alignment of the fruits should be such that the nipple extends horizontally between the adjoining fruits and not against another fruit. The fruit should be packed solidly together. The pack should be built up to a medium height, not so high as to cause injury when the lid is pressed down nor yet so low as to cause the fruit to rattle later on arrival at the market. The ends and middle should have paper guards to minimize injury on pressing down the lid.

Loading in Relation to Decay.—The manner of loading fruit either in railway cars or on ships may have an influence on decay. The load should be so braced as to insure against the boxes being broken and jostled about and fruit spilled out and injured with rough handling of the cars or severe pitching of the boat in storms. The stacks of boxes should, when possible, have spaces between them for ventilation. It should also be remembered that the air is usually several degrees warmer at the top than at the bottom of the space. In loading lemons, the boxes are usually set on end two tiers high in a car, with small spaces on the sides and slats nailed securely across the top to prevent jostling in transit.

Transit Conditions Influencing Decay in Lemons.—Details regarding the influence of transit conditions on decay, discussed on page 527, is applicable to lemons as well as to other Citrus fruits. Probably the most important conditions influencing such decay in transit have to do with temperature and ventilation; the lower the temperature down to certain limits the more will decay be retarded in development. If, however, temperatures of the fruit reach much below 40°F. for long periods, spotting and physiological derangement may result that will be even worse than a small amount of decay. Icing of cars in transit is discussed on page 527. It is not practiced so generally with lemons as with oranges, but is sometimes employed in extremely warm weather as a means of retarding decay in "tree-ripe" fruit. Delay in transit also has an important influence on decay. Cars are sometimes delayed by congested traffic or are diverted or re-sent from one market to another by the shipper, thus causing added delay.

Decay of Lemons on Arrival.—On the arrival at the railroad yards of a car destined for private sale, an inspector representing the growers' or packing associations climbs in on top of the stacks, loosens and pulls up sample boxes by means of tongs, opens and carefully unwraps the fruit from one-half of each box, making note of the percentage of decay, quality or other features and then repacks the fruit. In some cases, representatives of the transportation companies also inspect the fruit at the same time or independently. Two to five or more boxes may be inspected from each different lot or part of a car and the average taken. These reports are used in part as a basis for sales and are sent back as information to growers' associations.

If the car is destined for the auction market, the car is usually inspected after it is unloaded on the auction display floor. When the sample boxes are opened for display, the decay and other features are often estimated without unwrapping the fruit unless it is a period of heavy decay, at which time the representatives of both the growers and transportation companies may make careful inspections of certain cars.

The jobber or wholesaler, after purchase, may haul the boxes of fruit in trucks either direct from the car or from the floor of the auction display room. He may deliver it direct to retail stores on previous order, or he may first take it to his own store or basement, from which it is sold and redistributed later. If the decay is medium in amount, the jobber may merely open the boxes, take out the fruits easily gotten at from the top and put sound fruit in their places without repacking the whole box. This is termed "plugging." If the decay is considerable, and many of the wrappers on the sound fruit are wet, the whole box may be gone over, the decay taken out and the fruit repacked before selling to the retailer. Probably the largest factor in the price paid by the jobber or wholesaler is the actual or potential amount of decay in the fruit on arrival. By long experience, these men are keen and expert judges of the keeping qualities of fruit and are not often deceived by mere superficial appearances. They also learn to know by experience the uniformity and superior quality and freedom from decay of certain brands, and this experience is reflected in increased prices and demands for these brands. If any of the conditions previously discussed in the orchard, packing house and transit are favorable for development of decay, many different varieties of rots and spots may be seen in fruit on arrival (Fawcett 1925*a*). While green and blue mold are the decays most generally found, fruits that are weak or that have been stored long periods before shipment often show the largest percentage of Alternaria rot or "center rot." Other common forms of decay under these conditions are anthracnose spot and rot, sour rot, cottony rot, Botrytis rot, Phomopsis stem-end rot, Diplodia stem-end rot, Pleospora stem-end rot and internal decline. Minor forms of decay may be found, such as that due to Fusarium and Trichoderma.

A striking example of excessive amount and many kinds of decay on arrival is that experienced in the summer and fall of 1924. The amount, kind and distribution of decay in sixteen different shipments (Fawcett 1925*a*) in August, when the decay averaged 10 per cent but varied from 5 to 40 per cent, are of interest in this connection. Most of this fruit was weak and had been held ten to twelve weeks in the packing houses before shipment.

The percentage of decay for the sixteen lots averaged as follows:

Common green mold due to *Penicillium digitatum*	0.8
Blue-contact mold due to *P. italicum*	1.4
Alternaria rot due to *Alternaria citri*	5.9
Pliable, leathery, stem-end rots due to Phomopsis, Diplodia and Dothiorella	0.6
Anthracnose rots and firm, dry stem-end and side rots due to Colletotrichum, Pleospora, etc	0.6
Sour rot due to *Oöspora citri aurantii*	0.2
Botrytis rot due to *Botrytis cinerea*	0.04
Trichoderma rot due to *Trichoderma lignorum*	0.06
Rots too far advanced to be classified	0.5
Total	10.1

The main value of this example is to show the possibilities of decay when conditions in the orchard have made for weak fruit and when they have been held a long time in the packing houses, previous to shipment. In strong fruits or at different periods of the year, the relative percentages and kinds of decay would have been different.

A striking example of differences in decay in different cars is afforded by three cars of fruit arriving in Cincinnati on the same day.

The older fruit of car 1, which had been picked sixteen weeks previous, showed 39.1 per cent decay, 27 per cent of which was Alternaria or center rot. This Alternaria rot was increased to 37 per cent on cutting, showing that 10 per cent of the fruit affected with this rot was apparently sound on the exterior and could only be told by cutting. Cutting also showed 8 per cent with internal decline and 37 per cent with membranous stain.

TABLE 11.—DIFFERENCES IN DECAY IN RELATION TO AGE OF FRUIT

	Car 1		Car 2		Car 3	
Weeks elapsed from time of picking	16		11		6	
	Before cutting	After cutting	Before cutting	After cutting	Before cutting	After cutting
Common green mold	0.3	....	2.4	....	0.3	
Blue-contact mold	5	....	0	....	3.3	
Alternaria rot	27.0	37.0	1.7	9.0	0	2.0
Pliable, leathery stem-end rots	2.6	....	1.4	....	0	
Firm, dry rots (anthracnose, Pleospora rot, etc.)	3.0	....	0.8	....	0.3	
Sour rot	0.3	....	0	....	0	
Botrytis rot	0.3	....	0.3			
Internal decline	....	8.0	...	20.0	...	24.0
Membranous stain	....	37.0	...	6.0	...	2.0
Not identified	0.6					
Total	39.1	....	6.6	....	3.9	

This was one of the worst cars of fruit seen arriving on the markets. The third car of fruit picked only six weeks showed very little as compared with the other. This car had only 3.9 per cent visible decay, none of which was Alternaria rot. On cutting, 2 per cent showed Alternaria rot developing in the interior. There was 24 per cent internal decline and 2 per cent membranous stain. The second car picked eleven weeks before was between these two extremes as to amount of decay. The greater amount of internal decline as compared to membranous stain in the last two cars is reversed in the first car. This would be expected when it is remembered that internal decline is more of a summer trouble and develops on the trees before picking, while membranous stain is a trouble developing on fruit picked in winter or spring and develops in storage after picking. Car 1 was picked in the spring and would, therefore, be more likely to have a greater amount of membranous stain and less internal decline than cars 2 or 3. Both of these maladies tend to weaken the resistance of the fruit to other decays, especially Alternaria rot.

Decay of Lemons in Storage at the Markets.—During certain periods, lemon fruits are frequently stored by jobbers or wholesale dealers at the points of distribution near large markets awaiting higher prices. This frequently prolongs the period from picking to consumption beyond the normal life of the fruit and gives time and opportunity for many kinds of very slow, almost saprophytic types of decay. Most of the storage rooms at the markets are not built to afford the best conditions of storing lemons and are, therefore, usually much less favorable for such purpose than those in California at the points of production. An example of high percentage of decay is afforded by the following average of fifteen sample lots of lemon fruits that had been kept in basement storage at eastern points in July and August, 1924.

These storage rooms varied from about 60 to 70°F., but had been much cooler earlier in the spring and summer. The total time of storage in the different lots, counting from time of picking till they were placed on the market, varied from about 90 to 130 days, with an average of about 110 days.

Percentages of Decay in Storage

Common green mold	1.5
Blue-contact mold	0.7
Pink mold	0.1
Alternaria rot	8.9
Pliable, leathery, stem-end rots	1.1
Anthracnose rots and dry stem-end or side rots	1.1
Sour rot	0.5
Botrytis rot	0.1
Trichoderma rot	0.3
Not identified	2.0
Total	16.3

Of the total decay, a little more than half was Alternaria rot. Here the common green mold was twice as great as the blue-contact mold, the two together making about one-eighth of the total. The reverse was true in fruit arriving. The main value of this example is to give a general idea of the different kinds of decay, but is not to be taken as typical of all storage fruit. Some of the worst examples were examined. They show what is likely to happen in lemon fruits that are held too long in storage, especially in a year when the fruit tends to be weak from unfavorable conditions in the orchard.

Some lemon fruits are also held in cold storage. Temperatures below 40°F. are likely to produce spotting or "pox." The safest temperatures appear to be 42 to 45 or 50°F. (p. 528). If, however, forced ventilation is practiced, or if the fruit does not go into the cold storage too soon after picking, the lower temperatures may not be injurious. Certain physiological diseases may also be emphasized by temperatures below 40°F., such as membranous stain, peteca, red blotch, etc. Some of the kinds of decay seen in prolonged cold storage at 40 to 43°F. in California lemons, especially on the ripe lemon fruits in 1924, were green and blue molds, Botrytis, Sclerotinia, Alternaria rots, internal decline and membranous stain.

In Italian lemons said to have been held at about 36°F. for three months, the following were seen: green and blue molds, Alternaria rot, anthracnose rot, Botrytis rot, Phomopsis stem-end rot, Fusarium rot and Septoria spot.

Causes for Excessive Decay in Lemon Fruits on Arrival.—From the foregoing discussion, it is seen that the causes for decay are various and complex. Conditions of handling all along the way from trees to market, as well as the conditions previous to picking the fruit, may initiate decay or hasten or retard its development. Mechanical and chemical injuries, too high or too low temperatures, extremes of humidity and lack of ventilation may all contribute toward the troubles of decay.

Several examples of excessive decay in lemons for the season of 1924 have been given. Although carelessness in handling in some instances may have been partly responsible, the more important contributing factors were largely those that have to do with the physiology of the fruit itself brought about in part by conditions in the orchard, and in part by the length of time the fruit was held on the tree or in the packing house before shipments.

Some of the definite conditions in the orchard that probably contributed to decay may be mentioned:

1. The lack of moisture during the growing season in many sections, hindering the normal development of the fruit. Many orchards lacked water during winter and early spring; irrigation was delayed because rains were daily expected.

2. The dry winds, during the same season, not only weakened the fruit but produced scars and abrasions by whipping them about. The sections which usually escaped winds were visited with an unusual amount.

3. The delay in picking the fruit from the trees and delay in shipment afterwards. Much fruit was allowed to remain on the trees when it should have been picked. When it was picked, there was an added delay in many cases in storage at the packing house before it went forward. This was largely due to cool weather at the large markets, together with a large crop, so that fruit was held back waiting for warmer weather to increase the demand. This "time" or "age" factor was a most important one in this set of causes, since it gave time for the Alternaria or "center rot" and the stem-end rot fungi to get well under way.

4. Touches of frost in various sections weakened internally certain fruit which did not show any visible effect on the exterior.

Remedy for Excessive Decay.—The conditions mentioned before are in part preventable and in part non-preventable. Extreme care in handling will prevent a large part of the common-green and blue-mold decay initiated by mechanical injuries. The borax treatment appears to be a supplementary aid. The part that is due to the fruit being stored too long in the packing house or held too long on the tree may be prevented by refraining from shipping fruit of a certain age or degree of weakness.

The part due to unfavorable climatic conditions during the development of the fruit is, of course, largely beyond the grower's control. Part of its consequences can be avoided, however, by shipping only the stronger fruit and sending the weaker to the by-products plants. This last remedy can be successfully carried out only by cooperative agreement by a large percentage of the growers. This is now being put into effect by about 90 per cent of the California growers by an agreement (Ramsey 1925) "to send forward only fruit that will, as far as anyone can determine in advance, give the consumer satisfaction." To carry out this agreement, an agent is appointed with authority to determine what fruit in each packing house will be satisfactory for shipment. The remainder is to be turned over to the by-products plants. This is made possible by the fact that most of the lemon growers are affiliated cooperatively in one marketing organization.

BIBLIOGRAPHY

The following list of publications contain those referred to in the text by means of the surname of the author and date of publication, as for example, Barrett (1918). When more than one publication by the same author is referred to in a given year, italicized letters are added to the date, as Berger (1914*a*) Berger (1914*b*) etc. A few papers not specifically referred to in the text are also included.

In some of the papers listed will be found bibliographies to many other papers on this subject.

In the publication by Savastano (1910) for example will be found an extensive list of earlier Italian papers on Citrus diseases. Other early publications are cited by Swingle and Webber (1896) and McAlpine (1899).

Bibliographies on general subjects are given by Hume (1911) Coit (1915) and on more specialized subjects by Butler (1911), Fawcett (1908*a*, 1912*a*, 1915*a*, 1923*a*) Savastano (1923), Winston (1923) etc.

ADAM, D. B.: Experiments in Citrus fruit storage, *Journ. Dept. Agr. Victoria*, **21**: 307–317, 2 *figs.*, 1923.

ALDERTON, GEORGE E.: Treatise and handbook of orange-culture in Auckland, New Zealand. 76 *pp.*, Wellington, 1884.

AMUNDSEN, EDW. O.: Black rot of the navel orange, *Calif. Comn. Hort. Mo. Bull.*, **2**: 527–534, 1913.

ASHBY, S. F.: Leaf stalk rot caused by *P. parasitica* Dastur., *West Indian Bull.*, **18**: 70–73, 1920.

AVERNA-SACCA, ROSARIO: Molestias das laranjeira, *Bol. Agr. Sao Paulo.*, Ser., **18**: 334–346, 1917.

BAL, S. N.: *Macrosporium* (Fries) growing on *Citrus medica* (var. *acida*) and other species of Citrus, *Journ., Dept. Sci., Univ. Calcutta*, **2**: (Bot.) 1–2, 1 *pl.*, 1920.

BALLARD, C. W.: The elements of vegetable histology, 246 *pp.*, New York, 1921.

BANCROFT, C. K.: Fungi causing diseases of cultivated plants in the West Indies, *West Indian Bull.*, **10**: 235–268, 1910.

BARGER, WILLIAM R.: Treating oranges with borax solution for control of blue and green mold, *Calif. Citrogr.*, **10**: 149, 1925.

BARGER, WILLIAM R. AND HAWKINS, L. A.: Borax as a disinfectant for Citrus fruit, *Journ. Agr. Research*, **30**: 189–192, 1925.

BARRETT, J. T.: Some observations on withertip in 1914, Proc., Fruit Growers Convention, Calif. 45: 242–244, 1915*a*.

Fruit stain and withertip of Citrus. *Abs. in Phytopathology*, **5**: 293; *Science*, N. S., **42**: 582, 1915*b*.

Armillaria root rot of Citrus trees, *Calif. Citrogr.*, **3**: 77–78, 1918.

Dry root rot, *1st. Ann. Rpt. Calif. Citrus Inst.*, 1919–1920: 157, 1920.

Withertip, tear-stain, *Calif. Citrogr.*, **7**: 232–233, 1922.

Barrett, J. T. and Fawcett, H. S.: Citrus fruit spots, stains and blemishes, *Ann. Rpt. Calif. Agr. Exp. Sta.*, 1918–1919: 17, 1919.

Bartholmew, E. T.: Bearing of water relation to internal decline of lemons, *Calif. Citrogr.*, **7**: 126, 128–129, 1922.

Alterneria rot of lemons, *Calif. Citrogr.*, **8**: 262, 293, 294, 1923*a*.

Internal decline of lemons, *Amer. Journ. Bot.*, **10**: 117–126, 1923*b*.

Report on internal decline (endoxerosis) of lemons, *Calif. Citrogr.*, **10**: 274, 294, 308, 1925.

Bartholomew, E. T., Barrett, J. T. and Fawcett, H. S.: Internal decline of lemons, *Amer. Journ. Bot.*, **10**: 67–70, 1923.

Berger, E. W.: Whitefly control—introducing the friendly fungi, *Fla. Agr. Exp. Sta. Press Bull.*, 82. 2 *pp.*, 1908.

Whitefly studies in 1908, *Fla. Agr. Exp. Sta. Bull.*, 97. 43–71, 19 *figs.*, 1909.

Whitefly control, *Fla. Agr. Exp. Sta. Bull.*, 103. 5–28, 2 *figs.*, 1910.

Citrus canker in the Gulf Coast country, etc., *Rpt. Fla. State Hort. Soc.*, 1–6, 1914*a*.

History of Citrus canker, *Fla. Agr. Exp. Sta. Bull.*, 124. 27–30, 1914*b*.

Linseed oil bordeaux, *Fla. State Hort. Soc. Proc.*, **30**: 1–4, 1917.

Natural enemies of scale insects and whiteflies in Florida, *Fla. State Plant Bd. Quart. Bull.*, **5**: 141–154, 1921.

Berkeley, M. J. and Broome, C. E.: Enumeration of the fungi of Ceylon, *Journ. Linnean Soc. Bot.*, **15**: 82–85, 1876.

Bertoni, M. S.: Contribucion al estudio de la gomosis del naranjo, *Agronomia* (Puerto Bertoni), **5**: 77–89, Paraguay, 1911.

La gomosis de los Citrus y un nuevo nedio preventivo y curativo, *An. Cient. Paraguayos*, Ser. **2**: 408–421, 1919.

Bewley, W. F.: Diseases of glasshouse plants, 208 pp., London, 1923.

Birmingham, W. A. and Stokes, W. B.: Experiments for the control of *Armillaria mellea*, *Agr. Gaz. N. S. Wales*, **32**: 649–650, 1921.

Blanchard, V. F. and Hodgson, R. W.: Re-building frost-injured Citrus trees, *Calif. Citrogr.*, **8**: 263, 294, 295, 1923.

Boncquet, P. A.: June drop of oranges, *Citrus Leaves*, **2**: (10) 1–2, 15–17, 1922.

Borg, J. Orange culture and diseases, *Bull. Bot. Dept. Jamaica*, N. S. **7**: 129–142, 1900.

Briggs, L. J., Jensen, C. A. and McLane, J. W.: Mottle leaf of Citrus trees in relation to soil conditions, *Journ. Agr. Research*, **6**: 721–739, 1916.

The mulched-basin system of irrigated Citrus culture and its bearing on the control of mottle leaf, *U. S. Dept. Agr. Bull.*, 499. 31 *pp.*, 1917.

Briosi, G. and Farneti, R.: Intorno alla Ruggine Bianca dei limoni, *Atti dell'Ist, Bot. dell'Università di Pavia*, **10**: 1–60, 1904.

Briosi, G.: Intorno al mal di gomma degli agrumi (*Fusisporium limoni* Briosi), *Atti Accad. Lincei, Rend. Cl. Sci. Fis. Mat. e Nat.* Ser., 3ª: **2**: 485–496, 1878.

Briosi, S.: Bollet del Minist di agricolt. industr. e. commercio T. 9, Ser. **C**, 13 pp. (Rev. *Centralbl. f. Bakt.*, (1) 2 Abt. **42**: 102, 1914–1915), 1908.

Brittlebank, C.: Eruptive disease, or "Exanthema", of orange trees in Australia, *Journ. Dept. Agr. Victoria*, **10**: 401–404, 2 *pls.*, 1912.

The gray mould or *Botrytis* disease of Citrus trees, *Journ. Dept. Agr. Victoria*, **13**: 605–608, 7 *pls.*, 1915.

Brizi, U.: Sulla *Botrytis citricola* n sp parassita degli agrumi., *Atti. Accad. Lincei.*, Ser. **V**: *Rend.* **12**: 318–324. Roma, 1903.

Brooks, F. T. and Sharples, A.: Pink Disease, *Dept. of Agric. Federated Malay States Bull.*, 21. 27 *pp.*, 1914.

BROWN, THOS. W.: The propagation and cultivation of Citrus trees in Egypt, *Min. Agr. Egypt, Tech. and Scientific Service Bull.*, 44. 88 *pp.*, 33 *pl.*, 1924.

BURGER, O. F.: Decay in citrus fruits during transportation, *Calif. Comn. Hort. Mo. Bull.*, **9:** 365–370, 1920*a*.

Decay of Citrus fruits in transit., *Fla. Agr. Exp. Sta. Press Bull.*, 322. 1–2, 1920*b*.

Variations in *Colletotrichum gloeosporioides*, *Journ. Agr. Research*, **20:** 723–736, 1921.

Citrus diseases, *Rpt. Fla. Agr. Exp. Sta.*, year ending June 30, 1923, 52R–57R, 1923*a*.

Citrus stem-end rot, *Citrus Ind.*, **4:** 14, 1923*b*.

Melanose control, *Florida., Grower.*, **28:** (20) 7, 17, 1923*c*.

BURGER, O. F., DE BUSK, E. F. AND BRIGGS, W. R.: Preliminary report on controlling Melanose, *Fla. Agr. Exp. Sta. Bull.*, 167. 123–140, 1923.

BURT, E. S.: The Thelephoraceae of North America VII, *Ann. Missouri. Bot. Gard.*, **3:** 319–344, 1916.

BUTLER, E. J.: Fungi and disease in plants, 547 pp., Calcutta, 1918.

BUTLER, ORMOND: A Study on gummosis of Prunus and Citrus, with observations on squamosis and exanthema of the Citrus, *Ann. Bot.*, **25:** 108–153, 3 *figs.*, 3 *pls.*, 1911.

BYARS, L. P.: Notes on the Citrus-root nematode, *Tylenchulus semipenetrans* Cobb. *Phytopathology*, **11:** 90–94, 1921.

CAMP, A. F.: Convenient chambers for inoculation of plants where high humidity and moderate temperatures are required, *Phytopathology*, **11:** 510–512, 1921.

Citric acid as a source of carbon for certain Citrus fruit-destroying fungi, *Ann. Missouri Bot. Gard.*, **10:** 213–298, 1923.

CAMPANILE, G.: In di una malattia della frutta di mandarino, (*Cytosporina citriperda* Camp), *Le Staz. Sper. Agr. Ital.*, **55:** 5–12, 1922.

CARNE, W. M.: Citrus diseases, brown rot and leaf blight, *Journ. Dept. Agr. Western Australia*, Ser. 2, **4:** 519–522, 1924.

CARTER, C. N.: A powdery mildew on Citrus. *Phytopathology*, **5:** 193–196, 1915.

CAVARA, FRID: Note sur le parasitisme de quelques champignons destructeurs, *Revue Mycologique*, **3:** 177–180, 1891.

CHACE, E. M., WILSON, C. P. AND CHURCH, C. G.: Composition of California lemons, *U. S. Dept. Agr. Bull.* 993. 18 *pp.* 4 *figs.*, 1921.

CLAUSEN, R. E.: A new fungus concerned in withertip of varieties of *Citrus medica.*, *Phytopathology*, **2:** 217–234, 1912.

CLEMENTS, F. E.: Genera of fungi, 227 *pp.*, Minneapolis, 1909.

COBB, N. A.: Citrus-root nematode, *Journ. Agr. Research*, **2:** 217–230, 13 *figs.*, 1914.

COIT, J. E.: The brown spot of the navel orange, *Proc. Soc. Hort. Sci.*, **7:** 62–67, 1910.

Citrus fruits, 520 *pp.*, New York, 1915.

Citrus blast, a new disease, *Univ. Calif. Journ. Agr.*, **3:** 234–235, 1916.

COIT, J. E. AND BLANCHARD, V. F.: The shell-bark disease of lemon trees, *Calif. Citrogr.*, **7:** 259, 292, 1922.

COIT, J. E. AND HODGSON, R. W.: The June drop of Washington navel oranges, *Calif. Agr. Exp. Sta. Bull.* 290. 203–212, 1918.

An investigation of the abnormal shedding of young fruits of the Washington navel oranges, *Univ. Calif. Journ. Agr. Sci.*, **3:** 283–368, 1919.

COLE, C. F.: A new Citrus disease, *Pythiacystis citriophthora*, *Journ. Agr. Victoria*, **19:** 363–366, 1921.

COLLINS, F. C.: Practical tree surgery, *U. S. Dept. Agr.*, *Yearbook* 1913: 163–190, 1914.

COLLISON, S. E.: Citrus fertilizer experiments, *Fla. Agr. Exp. Sta. Bull.*, 154. 48 *pp.*, 1919.

COMES, O.: Crittogamia Agraria, **1:** 1–600, 17 *pl.*, Napoli, 1891.

Cook, M. T.: Gomosis, *Primer informe anual Estac. Cent Agr. Cuba*, 1904–1905; 154–156, 1906.

Diseases of Citrus fruits, *Diseases of Tropical Plants*, 116–130, London, 1913.

Cook, M. T. and Horne, W. T.: Diseases of the orange, *Estac. Centr. Agr. Cuba Bull.* 9. 33–40, 19 *pls.*, 1908.

Coons, G. H. and Nelson, Ray: The plant diseases of importance in the transportation of fruits and vegetables, *American Railway Perishable Freight Assoc. Circ.*, 473-A. 59 *pp.*, *illus.*, 1918.

Cotton, A. D.: The genus Atichia, *Bull. Misc. Inform. Royal Gardens Kew*, 2: 54–63, 1914.

Culbertson, J. D.: Preparing for the frost, *Calif. Citrogr.*, **7**: 4, 1922.

Curtiss, A. H.: Foot-rot, sore-shin, or gum disease, *Fla. Agr. Exp. Sta. Bull.*, 2. 29–35, 1888.

Darnell-Smith, G. P.: Control of black spot and brown spot in Citrus, *Agr. Gaz. N. S. Wales*, **27**: 844, 1916.

Root rot of fruit trees due to *Armillaria mellea*, *Dept. Agr. N. S. Wales Plant Diseases Leaflets*, 18. 4 *pp.*, 1920.

Darnell-Smith, G. P. and Mackinnon, Ewen: Fungus and other diseases of Citrus trees, *Dept. Agr. N. S. Wales, Farmers Bull.* 90. 2nd. Ed., 90–120, 1916.

Fungus and other diseases of Citrus trees, *Agr. Gaz. N. S. Wales*, **25**: 946–954, 4 *pl.*, 1914.

Dastur, J. F.: On *Phytophthora parasitica* nov. spec., a new disease of the castor oil plant, *India Dept. Agr. Memoirs Bot.*, Ser. **5**: 177–231, 10 *pls.*, 1913.

Phytophthora on *Vinca rosea*, *India Dept. Agr. Memoirs Bot.*, *Ser.*, **8**: 233–241, 14 *figs.*, 1916.

Davis, R. A.: Citrus growing in South Africa, 309 *pp.*, Cape Town, 1924.

Denny, F. E.: Hastening the coloration of lemons, *Journ. Agr. Research*, **27**: 757–769, 1924*a*.

Effect of ethylene upon respiration of lemons, *Bot. Gaz.*, **77**: 322–329, 1924*b*.

Doidge, Ethel M.: The origin and cause of Citrus canker in South Africa, *Union South Africa, Dept. Agr. Sci. Bull.* 8. 1–20, 1916.

A bacterial spot of Citrus, *Ann. Appl. Biol.* **3**: 4–81, 13 *pls.*, 1917.

The characteristics of Citrus canker and its eradication, *Union South Africa, Dept. Agr. Bull.*, 3. 9 *pp.*, 13 *figs.*, 1918.

A preliminary check list of plant diseases, *Bot. Survey South Africa*, Memoir, **6**: 1–56, 1924*a*.

Citrus diseases, *Davis's Citrus Growing in South Africa*, 200–240, Cape Town, 1924*b*.

Brown rot in Citrus fruits, (*Pythiacystis citrophthora* R. and E. Smith) *Union South Africa, Dept. Agr., Bull.* 27. 1925.

Doidge, E. M. and Butler, E. J.: The cause of Citrus scab, *Trans. British Mycological Soc.*, **10**: 119–121, 5 *figs.*, 1924.

Doryland, E. D.: Citrus canker investigation at the Singalong Experiment Station, *Philippine Agr. Rev.* (English Ed.), **9**: 133–135, 1916.

Effects of formalin-Bordeaux mixture on Citrus canker, *Philippine Agr. Rev.* (English Ed.), **10**: 51–54, 1917.

Dozier, H. L.: Insect pests and diseases of the Satsuma orange, *Gulf Coast Citrus Exchange Educational Bull.*, 1. 101 *pp.*, 1924.

Dracopoulos, J. N.: La gomosis de los Citrus, *Trabajo confeccionado en el Instituto Bacteriologico de la Provincia, Corrientes Imprenta del Estado*, 102 *pp.*, 1917.

Duggar, B. M.: Fungous diseases of plants, 508 *pp.* 240 *figs.*, Boston, 1909.

D'Utra, G.: Molestias, inimigos e tratamento das laranjeiras, *Bol. Agr. Sao Paula, Brazil*, Ser. 2, **6**: 351–363, 1901.

EAMES, A. J. AND MACDANIELS, L. H.: An introduction to plant anatomy, 364 *pp.*, New York, 1925.

EARLE, F. S.: The cultivation of Citrus fruits in Porto Rico, *Porto Rico Dept. Agr. Circ.* 28. 1–20. 1920.

EARLE, F. S. AND ROGERS, JOHN M.: Citrus pests and diseases at San Pedro in 1915, *Ann. Rpt. San. Pedro Citrus Pathol. Labor.* (Isle of Pines), 5–41, 19 *figs.*, 1915.

EDSON, H. A. AND SHAPOVALOV, M.: Parasitism of *Sclerotium rolfsii* on Irish potatoes, *Journ. Agr. Research*, **23**: 41–46, 1923.

ENGLER, A. AND PRANTL, K. (EDITORS): Fungi, *Die naturlicher Pflanzenfamilien*, I Teil. 1. Abteilung, 513 pp., 1897. 1**. Abteilung, 570 *pp.*, Leipzig, 1900.

ESSIG, E. O.: Withertip of Citrus trees, *Pomona College Journ. Economic Bot.*, **1**: 23–56, 7 *figs.*, 1911.

Injurious and beneficial insects of California, 2nd. Ed., *Calif. Comn. Hort., Mo. Bull* **4**: (4) Sup., 541 *pp.*, 1915.

EVANS, I. B. POLE: On the structure and life-history of *Diplodia natalensis*, n. sp., *Union South Africa, Transvaal Dept. Agr. Sci. Bull.*, 4. 18 *pp.*, 1910.

EVANS, I. B. POLE, THOMSON, MARY R. H. AND PUTTERILL, V. A.: Further investigations into the cause of wastage in export Citrus fruits from South Africa, *Union South Africa, Dept. Agr. Bull.*, 1. 48 *pp.*, 1921.

FAWCETT, G. L.: La verruga o "scab" de los Citrus (Citrus scab), *Revista Industrial y Agricola de Tucuman*, **10**: 124–128, 3 *figs.*, 1920.

La gomosis de los naranjos, *Revista Industrial y Agricola de Tucuman*, **12**: 149–151, 1922.

FAWCETT, HOWARD S.: Scaly bark, Citrus scab, gumming of Citrus, fungi parasitic on Citrus whitefly, *Rpt. Fla. Agr. Exp. Sta.* 1906–1907: 43–49, 1907.

Fungi parasitic upon *Aleyrodes citri*, *Special studies No.* 1, *Univ. of Florida*, 41 *pp.*, 19 *figs.*, 8 *pls.*, 1908*a*.

Citrus diseases; parasitic fungi on whitefly, *Rpt. Fla. Agr. Exp. Sta.*, 1907–1908: 64–75, 3 *figs.*, 1908*b*.

Scaly bark of citrus (a preliminary report), *Fla. Agr. Exp. Sta. Bull.* 98. 73–78, 3 *figs*, 1909*a*.

Stem-end rot of Citrus trees, *Fla. Agr. Exp. Sta. Press Bull.* 131. 2 *pp.*, 1909*b*.

Some diseases of Citrus trees, *Fla. State Hort. Soc. Proc.*, **22**: 75–87, 1909*c*.

An important entomogenous fungus, *Mycologia*, **2**: 164–168, 2 *pls.*, 1910*a*.

Cladosporium citri Mass. and *C. elegans* Penz. confused, *Mycologia*, **2**: 245–246, 1910*b*.

Stem-end rot, gummosis, nail-head rust, Citrus scab, *Aegerita webberi*, *Cephalosporium lecanii*, *Rpt. Fla. Agr. Exp. Sta.*, 1909–1910: 45–65, 1910*c*.

Stem-end rot of Citrus fruits (*Phomopsis* sp.), *Fla. Agr. Exp. Sta. Bull.* 107. 23 *pp.*, 9 *figs.*, 1911*a*.

Scaly bark or nail-head rust of Citrus, *Fla. Agr. Exp. Sta. Bull.*, 106. 1–41, 30 *figs.*, 1911*b*.

Citrus scab, *Fla. Agr. Exp. Sta., Bull.*, 109. 49–60, 7 *figs.*, 1912*a*.

The cause of stem-end rot of Citrus fruits (*Phomopsis citri n.* sp.), *Phytopathology*, **2**: 109–113, 6 *figs.*, 1912*b*.

Stem-end rot, black rot, Diplodia rot, *Diplodia natalensis* as a gum-inducing fungus, scab and *Aegerita webberi*, *Rpt. Fla. Agr. Exp. Sta.*, 1910–1911: 48–68, 3 *figs.*, 1912*c*.

Citrus galls, *Calif. Comn. Hort., Mo. Bull.*, **1**: 937–940, 1912*d*.

Fruit rots, *Calif. Comn. Hort. Mo. Bull.*, **1**: 649–653, 1912*e*.

Stem-end rot, combination inoculations, effect of spraying, gumming, *Diplodia natalensis* inoculations into trees, *Rpt. Fla. Agr. Exp. Sta.* 1911–1912: 64–92, 1913*a*.

Two fungi as causal agents in gummosis of lemon trees in California. *Calif. Comn. Hort. Mo. Bull.*, **2**: 601–617, 12 *figs.*; *Phytopathology*, **3**: 194–195, 1913*b*.

Tear staining of lemons, *Calif. Comn. Hort. Mo. Bull.*, **2**: 560–561, 1913*c*.

Orchard sanitation, *Calif. Comn. Hort. Mo. Bull.*, **2**: 371–374, 1913*d*.

Citrus diseases, *Eighth Ann. Rpt. Proc. Cuban Natl. Hort. Soc.*, 21–30, 1914.

Citrus diseases of Florida and Cuba compared with those of California, *Calif. Agr. Exp. Sta., Bull.* 262. 62 *pp.*, 24 *figs.*, 1915*a*.

The known distribution of *Pythiacystis citrophthora* and its probable relation to mal di gomma, *Phytopathology*, **5**: 66–67, 1915*b*.

Spotting of Citrus fruits due to the action of oil liberated from the rind, *Calif. Exp. Sta. Bull.*, 266. 259–269, 1916*a*.

Citrus scab, *Phytopathology*, **6**: 442–445, 1916*b*.

A Pythiacystis on avocado trees, *Phytopathology*, **6**: 433–435, 1916*c*.

Geographical distribution of Citrus diseases, Melanose and stem-end rot, *Johns Hopkins Univ. Circ.*, N. S., **3**: 388–391, 1917.

Citrus blast, *Calif. Citrogr.*, **5**: 3, 3 *figs.*, 1919.

Pythiacystis and Phytophthora, *Phytopathology*, **10**: 397–399, 1920.

Temperature relations of growth in certain parasitic fungi, *Univ. Calif. Publ. Agr. Sci.*, Ser., **4**: 183–232, 11 *figs.*, 1921*a*.

Some relations of temperature to growth and infection in the Citrus scab fungus, *Cladosporium citri*, *Journ. Agr. Research*, **21**: 243–254, 1921*b*.

Control of brown rot, *Calif. Citrogr.*, **7**: 232–233, 254, 1922*a*.

A new Phomopsis of Citrus in California, *Phytopathology*, **12**: 419–424, 1922*b*.

Citrus diseases, *Citrus Leaves*, **2**: (2), 5–7; (3), 5–6, 1922*c*.

Gummosis of Citrus, *Journ. Agr. Research*, **24**: 191–236, 8 *pls.*, 1923*a*.

Gum diseases of Citrus trees in California, *Calif. Agr. Exp. Sta. Bull.*, 360. 370-423, 15 *figs.*, 1923*b*.

Experiments in bridge grafting and inarching in connection with gummosis of Citrus, *Calif. Citrogr.*, **8**: 68, 95, 1923*c*.

Shell bark (decorticosis) of lemon trees, some investigations and observations, *Calif. Citrogr.*, **9**: 330, 1924.

The decay of Citrus fruits on arrival and in storage at eastern markets, *Calif. Citrogr.*, **10**: 79, 98, 103, 1925*a*.

Observations on bark diseases of Citrus in Sicily, *Phytopathology*, **15**: 41–42, 1925*b*.

Maintained growth rates in fungus cultures of long duration, *Ann. Appl. Biol.*, **12**, 191–198, 1925*c*.

Bark disease of Citrus trees in California, *Calif. Agr. Exp. Sta. Bull.*, 395. 61 *pp.*, 19 *pls.*, 1925*d*.

FAWCETT, H. S. AND BURGER, O. F.: A gum-inducing Diplodia of peach and orange, *Mycologia*, **3**: 151–153, 1911*a*.

Variety of *Cladosporium herbarum* on *Citrus aurantium* in Florida, *Phytopathology*, **1**: 164–166, 1911*b*.

FAWCETT, H. S., HORNE, W. T., AND CAMP, A. F.: Citrus blast and black pit, *Calif. Citrogr.*, **6**: 234, 3 *figs.* 1921.

Citrus blast and black pit, *Calif. Agr. Exp. Sta. Tech. Paper*, 5: 24 *pp.*, 6 *pls.*, 1923.

FAWCETT, H. S. AND RAMSEY, H. J.: Observations on lemon decays at eastern markets, *Calif. Citrogr.*, **10**: 12, 22, 1924.

FAWCETT, WM. AND RENDLE, A. B.: Citrus, *Flora of Jamaica*, **14**: part II, 183–190, 1920.

FERNOW, B. E.: The care of trees in lawns, streets and parks, 392, *pp.*, New York, 1910.

Ferrari, G. B.: Hesperides; Sive, *De Malorvm Avreorvm Cvltvra et Vsv Libri Quatuor*, 480 *pp.*, illus., Romae, 1646.

Ferraris, T.: Di un nuovo ifomicete parassita nei frutti di arancio, *Malpighia*, **13**: 368–381, 1900.

I parassiti vegetali della piante coltivate od utili, 1032 pp., Alba., 1913.

Fink, G. J.: Whitewashes and aqueous lime paints, *Journ. Ind. Eng. Chem.*, **14**: 503–511, 1922.

Floyd, B. F.: Problems in Citrus nutrition: fertilization, die back, melanose, *Rept. Fla. Agr. Exp. Sta.*, 1910–1911: 68–81, 5 *figs.*, 1912.

Experiments with Citrus Dieback, *Rpt. Fla. Agr. Exp. Sta.*, 1911–1912: 102–114, 1913.

Gumming of Citrus trees produced by chemicals, *Rpt. Fla. Agr. Exp. Sta.*, 1912–1913: 30–44, 2 *figs.*, 1914.

The air in the soil, *Fla. Agr. Exp. Sta. Press Bull.*, 247. 2 *pp.* 1916.

Dieback, or exanthema of Citrus trees, *Fla. Agr. Exp. Sta. Bull.*, 140. 31 *pp.*, 1917.

Floyd, B. F. and Stevens, H. E.: Melanose and stem-end rot, *Fla. Agr. Exp. Sta. Bull.*, 111. 16 *pp.*, 1912.

Fouqué, F.: Voyages Geólogiques Aux Acores. III. Les Cultures De San-Miguel, *Rev. Deux Moñdes*, tome **104**: 829–863, 1873.

Froggatt, W. W. and Gurney, W. B.: Insect pests, *Dept. Agr. N. S. Wales Farmers' Bull.* 90. (2nd Ed.) 77–89, 1916.

Fuller, C.: Insect pests, Davis' *Citrus Growing in S. Africa*, 241–278, Cape Town, 1924.

Fulton, H. R.: Decline of *Pseudomonas citri* in the soil, *Journ. Agr. Research.*, **19**: 207–223, 1920.

Relative susceptibility of Citrus varieties to attack by *Gloeosporium limetticolum* (Clausen), *Journ. Agr. Research.*, **30**: 629–635, 1925.

Fulton, H. R. and Bowman, J. J.: Preliminary results with the borax treatment of Citrus fruits for the prevention of blue mold rot, *Journ. Agr. Research.*, *28:* 961–968, 1924.

Fulton, H. R. and Winston, J. R.: Controlling blue mold rot of Citrus fruits with borax solution, *Fla. Grower*, **30**: (18), 7 *pp.*, 1924.

Gandara, G.: Enfermedades y plagas del naranjo, *Estac. Agr. Cent. Mexico, Bol.*, 111. 40 *pp.*, 62 *pls.*, 1920.

Garey, Thomas A.: Orange culture in California, 227 pp., San Francisco, 1882.

Gaümann, Ernst: Uber das *Septobasidium bogoriense* Pat., *Ann. Mycology.*, **20**: 160–173, 1922.

Grafe, Viktor, Gummisubstanzen Hemicellulosen, Pflanzenchleime, Pektinstoffe, Huminsubstanzen, *Abderhalden, Emil. Biochemisches Handlexikon*, Bd. **2**: 1–113, Berlin, 1911.

Gray, Geo. P.: Standard insecticides and fungicides versus secret preparations, *Calif. Agr. Exp. Sta. Circ.*, 141. 4 *pp.*, 1915.

Phenolic insecticides and fungicides, *Calif. Agr. Exp. Sta. Bull.*, 269. 329–381, 1916.

Gray, G. P. and Colby, S. E.: Economic poisons 1922 and 1923, *Calif. State Dept. Agr., Special Publ.* 44. 1–59, 1924.

Grossenbacher, J. G.: Some bark diseases of Citrus trees in Florida, *Phytopathology*, **6**: 29–50, 9 *figs.*, 1916.

Grossenbacher, J. G. and Duggar, B. M.: A contribution to the life-history, parasitism, and biology of *Botryosphaeria ribis*, *N. Y. Agr. Exp. Sta. Tech. Bull.*, 18. 113–190, 1911.

Gwynne-Vaughan, Helen: Fungi, ascomycetes ustilaginales, uredinales, *Cambridge Botanical Handbooks*, 232 *pp.* 1922.

Haberlandt, G.: Physiological plant anatomy, Translation by M. H. Drummond 777 *pp.*, New York, 1914.

Hara, K.: Small, brown, round spot disease, *Journ. Hort. Soc. Japan*, **29**: 9 (Translation by Tanaka in *Mycologia* **9**: 367–368), 1917.

Dark spot of summer orange, *Qua-Ju* (*Fruit Culture*), **188.** 22–24, 3 *figs.* (Rev. in *Bot. Abs.*, **1**: 215), 1918.

Harter, L. L. and Weimer, J. L.: Decay of various vegetables and fruits by different species of Rhizopus, *Phytopathology*, **12**: 205–212, 1922.

Hasse, Clara H.: *Pseudomonas citri*, the cause of Citrus canker, *Journ. Agr. Research*, **4**: 97–100, 1915.

Hauman-Merck, L.: Les parasites végétaux des plantes cultivées en Argentine, *Centralbl. f. Bakt.*, abt. 2, **43**: 420–454, 1915.

Hawkins, Lon A.: A physiological study of grapefruit ripening and storage, *Journ. Agr. Research*, **22**: 263–279, 1921.

Investigations of the freezing of Citrus fruits, quotations from address to Lemon Men's Club, *Calif. Citrogr.*, **10**: 181–182, 1925.

Hawkins, Lon, A. and Magness, J. R.: Some changes in Florida grapefruit in storage, *Journ. Agr. Research.*, **20**: 357–373, 1920.

Hedges, Florence, *Sphaeropsis tumefaciens* n. sp. The cause of the lime and orange knot, *Phytopathology*, **1**: 63–65, 1911.

Hedges, Florence and Tenny, L. S.: A knot of Citrus trees caused by *Sphaeropsis tumefaciens*, *U. S. Dept. Agr. B. P. I. Bull.*, 274. 75 *pp.*, 8 *figs.*, 10 *pls.*, 1912.

Hemmi, Takeo: On the pathogenic nature of Nishida's anthracnose fungus of Citrus, *Japanese Journ. Plant Pro.*, **8**: 173–177, 1921.

Hendrickson, A. H.: Oak fungus in orchard trees, *Calif. Agr. Exp. Sta. Circ.* 289. 13 *pp.*, 1925.

Hennings, P.: Fungi *S. Paulenses* I., *Hedwigia*, **41**: 104–134, 1902.

Higgins, B. B.: Gum formation with special reference to cankers and decays of woody plants, *Ga. Agr. Exp. Sta. Bull.* 127. 23–59, 15 *figs.*, 1919.

Higgins, J. E.: Citrus fruits in Hawaii, *Hawaii Agr. Exp. Sta. Bull.* 9. 7–31, 7 *figs.*, 3 *pls.*, 1905.

Hill, R. G. and Hawkins, Lon A.: Transportation of Citrus fruit from Porto Rico, *U. S. Dept. Agr. Bull.* 1290. 19 *pp.*, 1924.

Hobson, Geo.: Observations on the overseas markets during 1921 Citrus season, *Dept. Agr. Union South Africa. Bull.* 1. 48–61, 1922.

Hodgson, R. W.: Citrus blast—a new bacterial disease, *Calif. Comn. Hort. Mo. Bull.*, **6**: 229–233, 1917*a*.

Some abnormal water relations in Citrus trees of the arid southwest and their possible significance, *Univ. Calif. Agr. Sci.*, **3**: 37–54, 1917*b*.

An account of the mode of foliar abscission in Citrus. Univ. Calif. Agr. Sciences **6**: 417–428, 3 *figs.* 1918.

Saving the gophered Citrus tree, *Calif. Agr. Exp. Sta. Circ.* 273. 19 *pp.*, 1923.

Hori, S.: Kaukitsu-rui-soka-byo-shi [History of Citrus scab] *Shokubutsu Byogai Kowa dainihen nijukusho. Lecturnes on plant diseases*, **2**: 280–289, 1 *fig.*, 1916, Tokyo. Text in Japanese.

Horne, W. T.: Root rot of Citrus trees, *Proc. Thirty-seventh Fruit Growers Convention, Calif. Comn. Hort.*, 93–97, 1910.

Fungus root rot, *Calif. Comn. Hort. Mo. Bull.*, **1**: 216–225, 1912.

The oak fungus diseases of fruit trees, *Calif. Comn. Hort. Mo. Bull.*, **3**: 275–282, 1914.

Oak fungus or *Armillaria mellea* in connection with nursery stock, *Calif. Comn. Hort. Mo. Bull.*, **4**: 179–184, 1915*a*.

Wood decay in orchard trees, *Calif. Agr. Exp. Sta. Circ.*, 137. 9 *pp.*, 2 *pls.*, 1915*b*.

A Phomopsis in grapefruit from the Isle of Pines, W. I. with notes on *Diplodia natalensis*, *Phytopathology*, **12**: 414–418, 1922.

Hume, H. H.: Some Citrus troubles, *Fla. Agr. Exp. Sta. Bull.* 53. 145-173, 5 *figs.*, 6 *pls.*, 1900.

Anthracnose of the Pomelo, *Fla. Agr. Exp. Sta. Bull.* 74. 161–172, 1904.

Citrus fruits and their culture, 587 *pp.*, New York, 1911.

Hutchins, L. M. and Livingston, B. E.: Oxygen-supplying power of the soil as indicated by color changes in alkaline pyrogallol solution, *Journ. Agr. Research.*, **25**: 133–140, 1923.

Ideta, A.: Kankitsu no Kasabŷo (Scab of Citrus), "Nippon Shokubutsu byôrigaku" ("Handbook of the Plant Diseases of Japan") 4th Ed., 737-741, 2 *figs.* 1911, Tokyo. Text in Japanese.

Jaczewski, A.: Bureau of Mycology and Phytopathology, *Dept. Agr. Russia Yearbook, Plant Diseases and Injuries*—7th and 8th years (1911–1912), 423, 1917.

Janini, R. J.: The chief diseases and pests of the orange and lemon groves in Spain, *Intern. Rev. Sci. and Pract. Agr.*, N. S., **1**: 61–73, 2 *pls.*, 1923.

Jarvis, E.: A gumming disease affecting lemon fruits, *Queensland Agr. Journ.* N. S., **1**: 345–348, 1914.

Jehle, R. A.: Means of identifying Citrus canker, *Fla. State Plant Bd. Quart. Bull.*, **1**: 2–10, 9 *pls.*, 1916.

Susceptibility of non-citrus plants to *Bacterium citri*, *Phytopathology*, **7**: 339–344, 3 *figs*, 1917.

The effect of disinfectants upon *Bacterium citri*, *Fla. State Plant Bd., Quart Bull.*, **2**: 112–123, 1918.

Jenkins, Anna E.: The Citrus scab fungus, *Phytopathology*, **15**: 99-103, 4 *figs.*, 1925.

Johnston, J. R. and Bruner, S. C.: Enfermedades del naranjo y otras plantas citricas, *Bol. Estac. Exp. Agron. Cuba.* 38. 54 *pp.*, 15 *pls.*, 1918.

Jones, W. S.: The citron tree, "Fruit culture in foreign countries," *Rpt. Calif. State Bd. Hort.* 1890. 404–405, 1890.

Kelley, W. P.: The present status of alkali, *Calif. Agr. Exp. Sta. Circ.* 219. 10 *pp.*, 1920.

Kelley, W. P. and Cummins, A. B.: Composition of normal and mottled Citrus leaves, *Journ. Agr. Research.*, **20**: 161–191, 1920.

Kelley, W. P. and Thomas, E. E.: The effects of alkali on Citrus trees, *Calif. Agr. Exp. Sta. Bull.* 318. 305–337, 1920.

Kirk, Thomas: Diseases of lemon and other trees in New Zealand, 5 *pp*, Wellington, 1885.

Lee, Beatrice and Priestley, J. H.: The plant cuticle. I. Its structure, distribution and function, *Ann. Bot.*, **38**: 525–545, 12 *figs.*, 1924.

Lee, H. Atherton: A new bacterial Citrus disease, *Journ. Agr. Research.*, **9**: 1–8, 1917.

Further data on the susceptibility of rutaceous plants to Citrus canker, *Journ. Agr. Research*, **15**: 661–666, 4 *pls.*, 1918*a*.

Further data on the Citrus canker affection of the Citrus species and varieties at Lamao, *Philippine Agr. Rev.*, **11**: 200–206, 1918*b*.

Early occurrence of Citrus scab in Japan, *Phytopathology*, **8**: 551, 1918*c*.

Behavior of the Citrus canker organism in the soil, *Journ. Agr. Research*, **19**: 189 206, 2 *pls.*, 1920*a*.

Action of some fungicides on the Citrus canker organism, *Philippine Journ. Sci.*, **17**: 325–341, 1920*b*.

Black spot of Citrus fruits caused by *Phoma citricarpa* McAlpine, *Philippine Journ. Sci.*, **17**: 635–641, 4 *pls.*, 1920*c*.

The relation of stocks to mottled leaf of Citrus trees, *Philippine Journ. of Sci.*, **18**: 85–93, 3 *pls.*, 1921*a*.

The increase in resistance to Citrus canker with the advance in maturity of Citrus trees, *Phytopathology*, **11**: 70–73, 1921*b*.

Relation of age of Citrus tissues to the susceptibility to Citrus canker, *Philippine Journ. Sci.*, **20**: 331–339, 3 *pls.*, 1922.

A disease of Satsuma and Mandarin orange fruits caused by *Gloeosporium foliicolum* Nishida, *Philippine Journ. Sci.*, **22**: 603–614, 1923*a*.

California scaly bark and bark rot of Citrus trees in the Philippines, *Philippine Agr. Rev.*, **16**: 219–225, 7 *pls.*, 1923*b*.

Dry rot of Citrus fruits caused by a *Nematospora* species, *Philippine Journ. Sci.*, **24**: 719–733, 2 *pls.*, 1924.

The comparative resistance to foot rot of various Citrus species as root stocks, *Philippine Journ. Sci.*, **27**: 244–254, 1 *pl.*, 1925.

Lee, H. Atherton and Merrill, E. D.: The susceptibility of a non-rutaceous host to Citrus canker, *Science*, N. S., **49**: 499–500, 1919.

Lee, H. A. and Shino, A.: Citrus canker control experiments in Japan, *Philippine Journ. Sci.*, **20**: 121–150, 4 *pls.*, 1922.

Lee, H. Atherton and Yates, H. S.: Pink disease of Citrus, *Philippine Journ. Sci.*, **14**: 657–671, 7 *pls.*, 1919.

Leonian, Leon H.: Physiological studies on the genus, *Phytophthora*, *Amer. Journ. Bot.*, **12**: 444–498, 1925.

Lindau, G.: Die Pilze Fungi imperfecti, Rabenhorst's Krytogamen Flora von Deutschland Band I Abteilung VIII, 2 aufl., 1907.

Link, G. K. K. and Gardener, M. W.: Market pathology and market diseases of vegetables, *Phytopathology*, **9**: 497–520, 1919.

Lipman, C. B.: A contribution to our knowledge of the soil relationships with Citrus chlorosis, *Phytopathology*, **11**: 301–305, 1921.

Lipman, C. B. and Gordon, A.: Further studies on new methods in the physiology and pathology of plants, *Journ. Gen. Physiol.*, **7**: 615–623, 1925.

Lyon, H. L. and Lee, H. A.: Citrus canker in the Hawaiian Islands, *Phytopathology*, **11**: 377, 1921.

MacDougal, D. T., Richards, H. M. and Spoehr, H. A.: Basis of succulence in plants, *Bot. Gaz.*, **67**: 405–416, 1919.

Magness, J. R. and Diehl, H. C.: Physiological studies on apples in storage, *Journ. Agr. Research*, **27**: 1–38, 1924.

Mason, T. G.: Ligneous zonation and dieback in the lime (*Citrus medica* var. *acida*) in the West Indies, *Sci. Proc. Roy. Dublin Soc.*, **17**: N. S., 255–262, 4 *pls.*, 1923.

Massee, George: Fungi Exotici I, *Bul. Misc. Inform. Royal Gardens Kew*, No 138. 113–136, 1898.

Matz, J.: Citrus and pineapple fruit rots, *Porto Rico Dept. Agr. Bull.* 24. 12 *pp.*, 1920.

Mayet, M. V.: Une Maladie Affectant Les Citronniers dans l'Arrodissement de Calvi, *Ministere de l'agric. Bull.*, **5**: 449–456, Paris, 1891.

McAlpine, D.: Fungus diseases of Citrus trees in Australia, and their treatment, 132 *pp.*, 31 *pls.*, Melbourne, 1899.

McLean, F. T.: A study of the structure of the stomata of two species of Citrus in relation to Citrus canker, *Bull. Torrey Bot. Club.* **48**: 101–106, 1921*a*.

The permeability of Citrus leaves to water, *Philippine Journ. Sci.*, **19**: 115–128, 1921*b*.

McLean, F. T. and Lee, H. A.: Pressures required to cause stomatal infection with the Citrus canker organism, *Philippine Journ. Sci.*, **20**: 309–320, 2 *figs.*, 1922.

Merrill, E. D.: An interpretation of Rumphius's herborium Amboinense. *Manila Bureau of Sci.*, Publ. 9, 595 *pp.*, 1917.

Merrill, E. D. and Lee, H. A.: A consideration of the species *Citrus maxima* (Burm.) Merrill, *Amer. Journ. Bot.*, **11**: 382–384, 1924.

Miller, C. C.: Injurious lemon roots, *Calif. Citrograph*, **4**: 356, 359, 1919.

Mills, J. W.: Citrus fruit culture, *Calif. Agr. Exp. Sta. Bull.* 138. 46 *pp.*, 23 *pls.*, 1902.

Miyabe, K. and Sawada, K.: On fungi parasitic on scale-insects found in Formosa, *Journ. Coll. Agr. Tohoku Imperial Univ. Sapporo*, Japan, **5**: 73–90, 1913.

Moniz da Maia, R.: Um novo oomyceta parasita de árvores do género Citrus, *Revista Agron.* (Lisbon), IV, **1**: 2 *pls.*, 1925.

Moore, T. W.: Treatise and handbook of orange culture in Florida, 2nd Ed., 184 pp., New York, 1881.

Morrill, A. W. and Back, E. A.: Natural control of white flies in Florida, *U. S. Dept. Agr. Bur. Ent. Bull.*, 102. 78 *pp.*, 9 *pls.*, 1912.

Morrill, A. W. and Yothers, W. W.: The treatment of canvas to prevent mildew, *Calif. Citrogr.*, **4**: 220, 221, 1919.

Nishida, T.: Kankitsu no Shippei (Diseases of Citrus fruits), *Kankitsu* (*Citrus fruits*) **1**: (3,) 3–7, 1903*a*.

Kankitsu no sokabyô (Citrus scab among orange trees). *Dai-nippon Nokwaiho* (*Journ. Agr. Soc. Japan*), **23**: (258) 1–4, 1903*b*. Text in Japanese, Shinpen kankitsu byôgai to yobôhô (New treatise on Citrus disease and prevention), Tokyo, 1914.

Noack, F.: Pilzkrankheiten der orangenbaüme in Brazilian, *Zeitschr. Pflanzenkr.*, **10**: 321–335, 1900.

Nowell, Wm.: Rosellinia root diseases in the Lesser Antilles, *West Indian Bull.*, **16**: 31–71, 1917*a*.

The fungi of internal boll disease, *West Indian Bull.*, **16**: 152–159, 1917*b*.

A root diesease of cacao in Trinidad—*Rosellinia pepo.*, *Bull. Dept. of Agr. Trinidad and Tobago*, **18**: 178–199, 1919.

Diseases of crop plants in the Lesser Antilles, *West Indian Committee*, 383 *pp.*, London, 1923.

Onda, T.: Kankitsu no Kasabyô ni tsukite (On scab of Citrus), *Kwaju* (*Fruit tree*), 40. 20–23; 41. 16–19, 1905. Text in Japanese.

Osborn, T. G. B. and Samuel, G.: Some new records of fungi for South Australia, Part 2, *Trans. Roy. Soc. So. Austr.*, **46**: 166–180, 1922.

Parkin, John: Fungi parasitic upon scale insects (*Coccidae* and *Aleurodidae*): a general account with special reference to Ceylon forms, *Ann. Roy. Bot. Gard., Peradeniya*, **3**: 11–82, 4 *pls.*, 1906.

Patterson, Flora W. and Charles, Vera K.: Some fungous diseases of economic importance, *U. S. Dept. Agr. Bur. Plant Ind. Bull.*, 171. 13–14, 1910.

Peets, E.: Practical tree repair, 205 *pp.*, New York, 1913.

Peglion, V.: Uber die *Nematospora coryli* Pegl., *Centralbl. f. Bakt.*, Abt 2, **7**: 754–761, 1901.

Peltier, Geo. L.: Susceptibility and resistance to Citrus canker of the wild relatives, Citrus fruits and hybrids of the genus Citrus, *Journ. Agr. Research*, **14**: 337–357, 1918.

Influence of temperature and humidity on the growth of *Pseudomonas citri* and its host plants and on infection and development of the disease, *Journ. Agr. Research*, **20**: 447–506, 1920.

Peltier, Geo. L. and Frederich, Wm. J.: Relative susceptibility to Citrus canker of different species and hybrids of the genus Citrus, including the wild relatives, *Journ. Agr. Research*, **19**: 339–362, 1920.

Further studies on the relative susceptibility to Citrus canker of different species and hybrids of the genus Citrus, including the wild relatives. *Journ. Agr. Research*, **28**: 227–239, 1924*a*.

Relation of environmental factors to Citrus scab caused by *Cladosporium citri* Massee, *Journ. Agr. Research*, **28**: 241–254, 1924*b*.

Effects of weather on the world distribution and prevalence of Citrus canker and Citrus scab, *Journ. Agr. Research*, **32**: 147–164, 1926.

Peltier, Geo. L. and Neal, David C.: Overwintering of the Citrus-canker organism in the bark tissue of hardy Citrus hybrids, *Journ. Agr. Research*, **14**: 523–524, 1918.

Penzig, O.: Studi botanici sugli agrumi e sulle piante affini, 590 *pp.*, 58 *pls.*, Roma, 1887.

Petch, T.: Revisions of Ceylon Fungi, *Ann. Roy. Bot. Gard.*, Peradeniya, Ceylon, **4**: 21–68; 374–444, 1910.

Physiology and diseases of *Hevea brasiliensis*, 268 pp., London, 1911.

The genera *Hypocrella* and *Aschersonia*, *Ann. Roy. Bot. Gard.*, Peradeniya, Ceylon, **5**: 521–537, 1914*a*.

Notes on fungus diseases, *Yearbook Ceylon Agr. Soc.*, 1914, 65–67, 1914*b*.

Citrus mildew, *Phytopathology*, **5**: 350–352, 1915.

Citrus mildew: a correction; *Phytopathology*, **9**: 266, 1919.

Studies in entomogenous fungi: II. The genera *Hypocrella* and *Aschersonia*, *Ann. Roy. Bot. Gard.*, Peradeniya, Ceylon, **7**: 167–278, 4 *pls.*, 1921*a*.

Studies in entomogenous fungi, *Trans. Brit. Mycol. Soc.*, **7**: 89-132, 133–167, 2 *pls.*, 1921*b*.

Studies in entomogenous fungi: V. *Myriangium*. *Trans. Brit. Mycol. Soc.*, **10**: 45–80, 2 *pls.*, 1924.

Petri, L.: Sul modo di diffondersi del mal dell' inchiostro del Castagno e sui mezzi piu efficaci per combatterlo, *Nuovi Ann. Min. Agr. Italy*, **3**: 3–19, 4 *figs.*, 1923.

State attuale di alcuni problemi di fitopatologia, *Conferenza tenuta in Rome al XVIII congresso delle cattedre ambutant di agricoltura Italiane* 10 *maggio*, 16 *pp.*, 1924.

L'agente del marciume radicole degli agrumi, *Annali del R. Intituto Sup. Agrario e Forestale*, Ser. 2, **1**: 7 *pp.*, 1925*a*.

Osservazioni biologiche sulla "Blepharospora combivora," *Ann. R. Instuto Sup. Agrario e Forestale*, Ser. 2, **1**: 7 *pp.*, 1925*b*.

Pierce, N. B.: Black rot of navel orange, *Calif. Cultivator*, **17**: 181, 1901.

Black rot or navel rot of orange, *Bot. Gaz.*, **33**: 234–235, 1902.

Phillips, Edith H., Smith, Elizabeth H. and Smith, Raplh E.: Fig smut, *Calif. Agr. Exp. Sta. Bull.*, 387. 38 *pp.*, 1925.

Plakidas, A. G.: Fusarium rot of the peach, *Phytopathology*, **15**: 92-98, 1925.

Pope, W. T.: The acid lime fruits in Hawaii, *Hawaii Agr. Exp. Sta. Bull.*, 49. 20 *pp.*, 1923.

Powell, G. H.: The decay of oranges while in transit from California, *U. S. Dept. Agr., Bur. Plant. Ind., Bull.*, 123. 71 *pp.*, 1908.

Cooperation in the handling and marketing of fruit, *U. S. Dept. Agr. Yearbook*, 1910, 391–406, 1911.

Prillieux, Ed.: Etude sur la formation de la gomme dans les arbres fruitiers, *Compt. Rend. Acad.* [Paris], **78**: 135-137, 1874.

Prizer, J. A.: Some experiments in treating Citrus trees for gummosis and heart-rot, *Calif. Comn. Hort. Mo. Bull.*, **4**: 7–19, 1915.

Putterill, V. A.: Plant diseases in the Western Cape Province XI, *Journ. Agr. Union South Africa*, **7**: 403–406, 4 *figs.*, 1923.

Quayle, H. J.: Citrus fruit insects, *Calif. Agr. Exp. Sta. Bull.*, 214. 439–512, 74 *figs.*, 1911.

Red spiders and mites of Citrus trees, *Calif. Agr. Exp. Sta. Bull.*, 234. 479–530, 35 *figs.*, 1912.

Citrus fruit insects in Mediterranean countries, *U. S. Dept. Agr. Bull.*, 134. 35 *pp.*, 1914.

The control of Citrus insects, *Calif. Agr. Exp. Sta. Circ.*, 129. 35 *pp.*, 1915.

Quayle, H. J. and Tylor, A. R.: The use of the fungus Isaria for the control of the black scale, *Calif. Comn. Hort. Mo. Bull.*, **4**: 333–338, 1915.

Ramsey, H. J.: Handling and shipping Citrus fruits in the Gulf States, *U. S. Dept. Agr. Farmers' Bull.*, 696. 28 *pp.*, 1915.

Need of care to prevent blue mold decay in transit, *Calif. Citrogr.*, **6**: 170–171, 1921.

Economic lessons from 1924 lemon crop, *Calif. Citrogr.*, **10**: 197, 216, 1925.

Rant, A.: Studies on *Corticium javanicum*. *Bull. Jard. Bot. Buitenzorg*, Ser. 2. **4**: 50 *pp.*, 1912.

Reed, H. S.: Observations on the fruit industry in Costa Rica, *Calif. Citrogr.*, **7**: 261, 292, 1922.

Reed, H. S. and Haas, A. R. C.: Effect of sodium chloride and calcium chloride upon growth and composition of young orange trees, *Calif. Agr. Exp. Sta. Tech. Paper*, **4**: 20 *pp.*, 6 *pls.*, 1923*a*.

Growth and composition of orange trees in sand and soil cultures, *Journ. Agr. Research*, **24**: 801–814, 1923*b*.

Studies on the effects of sodium, potassium and calcium on young orange trees, *Calif. Agr. Exp. Sta. Tech. Paper*, **11**: 23 *pp.*, 1923*c*.

Nutrient and toxic effects of certain ions on Citrus and walnut trees with special reference to the concentration and PH of the medium, *Calif. Agr. Exp. Sta. Tech. Paper*, **17**: 75 *pp.*, 1924.

Rehm, H.: New fungi occurring on orange leaves, *Pomona Col. Journ. Econ. Bot.*, **1**: 106, 1911.

Reinking, O. A.: Philippine economic plant diseases, *Philippine Journ. Sci.*, **13**: 165–274, 1918.

Diseases of economic plants in Southern China, *Philippine Agr.*, **8**: 109–136, 1919.

Citrus diseases of the Philippines, So. China, Indo-China and Siam, *Philippine Agr.*, **9**: 121–185, 1921.

Ridgway, Robert: Color standards and color nomenclature, 44 pp., 53 *pls.*, 1115 colors, Washington, D. C., 1912.

Rogers, J. M. and Earle, F. S.: A simple and effective method of protecting Citrus fruits against stem-end rot, *Phytopathology*, **7**: 361–367, 1917.

Rolfs, P. H.: Withertip and other diseases of Citrus trees and fruits, *U. S. Dept. Agr. Bur. Plant Ind. Bull.*, 52. 9–20, 1 *fig.*, 6 *pls.*, 1904.

Diseases of Citrus: Withertip, *Fla. State Hort. Soc. Proc.*, **18**: 29–31, 1905.

Rolfs, P. H. and Fawcett, H. S.: Fungus diseases of scale insects and whitefly, *Fla. Agr. Exp. Sta. Bull.*, 94. 17 *pp.*, 21 *figs.*, 1908.

Fungus diseases of scale insects and whitefly, *Fla. Agr. Exp. Sta. Bull.*, 119. 69–82, 19 *figs.*, 1913.

Rolfs, P. H., Fawcett, H. S. and Floyd, B. F.: Diseases of Citrus fruits, *Fla. Agr. Exp. Sta. Bull.*, 108. 27–47, 13 *figs.*, 1911.

Rounds, M. B.: Individual tree care, *Ann. Rpt. Calif. Citrus Institute*, 1921–1922: 54–60, 1922.

Savastano, L.: Gommose caulinaire et radicale dans les aurantiacées, amygdalées, le figuier, l'oliveir et noircissement du noyer, *Compt. Rend. Acad. Sci. (Paris)*, **99**: 987–990, 1884.

Gommosi degli agrumi, *Patologia arborea applicata, lezione*, 20. 127–141, Napoli, 1910.

Le suberosi ed il gruppo delle malattie costituzionali settoriali nei frutti degli agrumi, *Ann. R. Staz. Sper. Agrumic. e Fruttic. Acireale*, **4**: 105–112, 1917.

Gommosi secca negli agrumi, *Boll. R. Staz. Sper. Agrumic. e Fruttic. Acireale*, N41. 5–7, 1921.

Studi ed esperimenti sul Marciume Radicale Degli Agrumi, *Ann. R. Staz. Sper. di Agrumic. e. Fruttic. Acireale*, **6**: 125–138, 6 *pls.*, 1922*a*.

Contributo allo studio del male dello scopaccio negli agrumi, *Ann. R. Staz. Sper. Agrumic. e Fruttic. Acireale*, **6**: 119–124, 6 *pls.*, 1922*b*.

Delle epidemie italiane del mal secco negli agrumenti, albicoccheti ficheti noceti e gelseti, *Ann. R. Staz. Sper. Agrumic. e Fruttic. Acireale*, **7**: 89–170, 6 *pls.*, 1923.

Schneider, Albert: A parasitic saccharomycete of the tomato, *Phytopathology*, **6**: 395–399, 1916.

Further note on a parasitic saccharomycete of the tomato, *Phytopathology*, **7**: 52–53, 1917.

Shamel, A. D., Pomeroy, C. S. and Caryl, R. E.: Pruning Citrus trees in the southwest, *U. S. Dept. Agr. Farmers' Bull.*, 1333. 32 *pp.*, 1923.

Bud selection as related to quality of crop in Washington Navel Orange, *Journ. Agr. Research*, **28**: 521–525, 1924.

Shamel, A. D., Scott, L. B., Pomeroy, C. S. and Dyer, C. L.: Citrus-fruit improvement—a study of bud variation in the Eureka Lemon, *U. S. Dept. Agr. Bull.*, 813. 87 *pp.*, 1920*a*.

Citrus-fruit improvement a study of bud variation in the Lisbon lemon, *U. S. Dept. Agr. Bull.*, 815. 70 *pp.*, 1920*b*.

Shear, C. L.: Pathological problems in the distribution of perishable plant products, *Mem. Brooklyn Bot. Gard.*, **1**: 415–422, 1918*a*.

Pathological aspects of the federal fruit and vegetable inspection service, *Phytopathology*, **8**: 155–160, 1918*b*.

Shear, C. L., Stevens, N. E. and Wilcox, M. S.: *Botryosphaeria* and *Physalospora* on currant and apple, *Journ. Agr. Research*, **28**: 589–598, 1924.

Botryosphaeria and *Physalospora* in the Eastern United States, *Mycologia*, **17**: 98–107, 1925.

Sherbakoff, C. D.: Buckeye rot of tomato fruit, *Phytopathology*, **7**: 119–129, 5 *figs.*, 1917.

Siemashko, V.: Contribution for a mycological flora of the District of Suchum (Russia), (*Abst. Internat. Inst. Agr.* Rome, **7**: 611–612, 1916), 1915.

Smith, C. O.: Cottony mold of lemons, *Calif. Cult.*, **35**: 196, 197, 2 *figs.*, 1910.

Further proof of the cause and infectiousness of crown gall, *Calif. Agr. Sta. Bull.*, 235. 531–557, 1912.

Black pit of lemon, *Phytopathology*, **3**: 277–281, 1913.

Cottony rot of lemons in California, *Phytopathology*, **6**: 268–278, 1916*a*.

Cottony rot of lemons in California, *Calif. Agr. Exp. Sta. Bull.*, 265. 237–258, 11 *figs.*, 1916*b*.

Sour rot of lemon in California, *Phytopathology*, **7**: 37–41, 1917.

Smith, R. E.: The "soft spot" of oranges, *Bot. Gaz.*, **24**: 103–104, 1897.

Botrytis and Sclerotinia, *Bot. Gaz.*, **29**: 369–407, 3 *pls.*, 1900.

The parasitism of *Botrytis cinerea*, *Bot. Gaz.*, **33**: 421–436, 1902.

Report of the Plant Pathologist to July, 1906, *Calif. Agr. Exp. Sta. Bull.*, 184. 221–258, 1907.

Report of the plant pathologist and superintendent of southern California stations, July 1, 1906 to June 30, 1909, *Calif. Agr., Exp. Sta. Bull.*, 203. 63 *pp.*, 1909.

The investigation of "physiological" plant diseases, *Phytopathology*, **5**: 83-93, 1915.

Smith, R. E. and Butler, O.: Gum disease of Citrus trees in California, *Calif. Agr. Exp. Sta. Bull.*, 200. 235–270, 14 *figs.*, 1908.

Smith, R. E. and E. H.: A new fungus of economic importance, *Bot. Gaz.*, **42**: 215–221, 1906.

California plant diseases, *Calif. Agr. Exp. Sta. Bull.*, 218. 1039–1193, 102 *figs.*, 1911.

Further studies on Pythiaceous infection of deciduous fruit trees in California, Reprint, *Phytopathology*, **15**: 389–404, 6 *figs.*, 1925.

Smith, R. E., Ramsey, H. J., Smith, E. H., Babcock, E. B. and Smith, C. O., The brown rot of the lemon, *Calif. Agr. Exp. Sta. Bull.*, 190. 70 *pp.*, 29 *figs.*, 1 *col. pl.*, 1907.

Sorauer, Paul: Einige beobachtungen uber gummibildung, *Landw. Vers. Stat.*, **15**: 454–465, 1872.

South, F. W.: The control of scale insects in the British West Indies by means of fungoid parasites, *West Indian Bull.*, **11**: 1–30, 1910*a*.

Root disease of cacao, lime and other plants, *Agr. News*, West Indies, **9**: 366–367, 1910*b*.

Speare, A. T.: Natural control of the Citrus mealybug in Florida, *U. S. Dept. of Agr. Bull.*, 1117. 18 *pp.*, 1 *pl.*, 2 *figs.*, 1922.

Speare, A. T. and Yothers, W. W.: Is there an entomogenous fungus attacking the Citrus rust mite in Florida? *Science*, **60**: 41–42, 1924.

Spegazzini, Carlos: Sobre algunas enfermedades y hongos que afectan las plantas de "Agrios" en el Paraguay, *Anal. Soc. Cient.* Argent., tomo, **90**: 155-188, 1920.

Springer, J. R.: Insects, pests and diseases in a nursery and their control, *Fla. Grower*, **29**: (4) 7, 20, 21, 1924.

Sterbeeck, Franciscus Van: Citricultura oft Regeringhe Der Uythemische Boomen te Weten Oranien, Citroenen, Limoenen, Granaten, Laurieren En Andere, 296 *pp.*, Antwerp., 1682.

Steiner, G., and Heinly, Helen: The possibility of control of *Heterodera radicola* and other plant-injurious nemas by means of predatory nemas, etc., *Journ. Wash. Acad. Sci.*, **12**: 367–386, 1922.

Stirling, F.: Eradication of Citrus canker, *Fla. Agr. Exp. Sta. Bull.*, 124. 44–53, 1914.

Stevens, F. L.: The fungi which cause plant disease, 754 *pp.*, New York, 1913.

Stevens, H. E.: Melanose and stem-end rot, *Fla. Agr. Exp. Sta. Press Bull.*, 199. 2 *pp.*, 1912.

Citrus canker, *Fla. Agr. Exp. Sta. Bull.*, 122. 113–118, 1914*a*.

Studies of Citrus canker, *Fla. Agr. Exp. Sta. Bull.*, 124. 31–43, 1914*b*.

Citrus canker III, *Fla. Agr. Exp. Sta. Bull.*, 128. 20 *pp.*, 1915.

Florida Citrus diseases, *Fla. Agr. Exp. Sta. Bull.*, 150. 96 *pp*, 54 *figs.*, 1918*a*.

Melanose II, *Fla. Agr. Exp. Sta. Bull.*, 145. 103–116, 1918*b*.

Lightning injury to Citrus trees in Florida, *Phytopathology*, **8**: 283–285, 1918*c*.

Stevens, Neil E.: *Physalospora malorum* on currant, *Journ. Agr. Research*, **28**: 583–587, 1924.

Stevens, Neil E. and Jenkins, Anna E.: Occurrence of the currant cane blight fungus on other hosts, *Journ. Agr. Research*, **27**: 837–843, 1924.

Stevens, N. E. and Wilcox, Marguerite S.: The Citrus stem-end rot "Diplodia;" its life history and relation to *Sphaeropsis malorum*, *Phytopathology*, **15**: 332–340, 1 *pl.*, 1925.

Stevens, W. C.: Plant anatomy, 398 *pp.*, Philadelphia, 1924.

Stevenson, John A.: Citrus Diseases of Porto Rico, *Journ. Dept. Agr. Porto Rico*, **2**: 43–123, 23 *figs.*, 1918*a*.

A check list of Porto Rican fungi and a host index, *Journ. Dept. Agr. Porto Rico*, **2**: 125–264, 1918*b*.

Stubenrauch, A. V., Ramsey, H. J. and Tenny, Lloyd, S.: Factors governing the successful shipment of oranges from Florida, *U. S. Dept. Agr. Bull.*, 63. 50 *pp.*, 1914.

Sumstine, D. R.: Studies in North American Hyphomycetes, The tribe *Oosporeae*, *Mycologia*, **5**: 45–61, 1913.

Swingle, Walter T.: Citrus, *Bailey, L. H. Standard Cyclopedia of Hort.*, **2**: 780–785, 1914.

Swingle, Walter, T. and Kellerman, Maude: *Citropsis*, a new tropical African genus allied to Citrus, *Journ. Agr. Research*, **1**: 419–436, 1914.

Swingle, Walter, T., Robinson, T. Ralph, and May, Eugene, Jr.: Quarantine procedure to safeguard the introduction of Citrus plants; a system of aseptic plant propagation, *U. S. Dept. Agr., Dept., Circ.*, 299. 15 *pp.*, 1924.

Swingle, Walter T. and Webber, Herbert J.: The principal diseases of Citrous fruits in Florida, *U. S. Dept. Agr. Div. Veg. Phys. and Path. Bull.*, 8. 42 *pp.*, 6 *figs.*, 8 *pls.*, 1896.

Tanaka, T.: A brief history of the discovery of Citrus canker in Japan and experiments in its control, *Fla. State Plant Bd. Quart. Bull.*, **3**: 1–15, 1918*a*.

Septobasidium acaciae Sawada, *Mycologia*, **10**: 88–89, 1918*b*.

Notes and translations viii, *Mycologia*, **12**: 25–32, 1920.

A brief history of Citrus scab in Japan, *Phytopathology*, **13**: 492–495, 1923.

Taubenhaus, J. J.: Recent studies on *Sclerotium rolfsii Journ. Agr. Research*, **18**: 127–138, 1919.

Thom, Charles: Cultural studies of species of Penicillium, *U. S. Dept. Agr. Bur. An. Ind. Bull.*, 118. 107 *pp.*, 1910.

Thom, Charles and Currie, J. N.: *Aspergillus niger* group, *Journ. Agr. Research*, **7**: 1–15, 1916.

Thom, Charles and Church, Margaret B.: *Aspergillus Flavus, A. Oryzae* and associated species, *Amer. Journ. Bot.*, **8**: 103–126, 1921.

Thomas, E. E.: A preliminary report of a nematode observed on Citrus roots and its possible relation with the mottled appearance of Citrus trees, *Calif. Agr. Exp. Sta. Circ.*, 85. 1913.

The Citrus Nematode, *Tylenchulus semipenetrans*, *Calif. Agr. Exp. Sta. Tech. Paper*, 2. 19 *pp.*, 8 *pls.*, 1923.

Thomson, Mary R. H., Putterill, V. A. and Hobson, Geo.: Investigations on export Citrus fruit from South Africa during 1921, *Union So. Africa, Dept. Agr. Bull.*, 1. 61 *pp.*, 1922.

Tower, W. V.: Citrus Scab, *Porto Rico Agr. Exp. Sta. Ext. Note*, 53, and *Ann. Rept.*, 1922. 13, 14, 1923.

Trabut, L.: La Melanose des mandarines, *Acad. Sci. Paris Comp. Rend.*, **126**: 546–550, 1898.

"Les Taches Noires des Mandarines," *Bull. Agr., de L'Algerie et Tunisie*, **7**: 112, 113, 1901.

Dépérissement des oranges causé par un nématode, *Compt. Rend. Acad. Agric. France*, **1**: 222, 1915.

Tschirch, A. and Oesterle, O.: Anatomischer atlas der pharmakognoske und nahrungsmittelkunde, 299–306, Leipzig, 1895.

Underwood, L. M.: Diseases of the orange in Florida, *U. S. Dept. Agr. Journ. Mycology*, **7**: 27–36, 1891.

Voglino, P.: I funghi parassiti piu daunosi piante Coltivati osservati nella provincia di Torino e regioni vicine, *Acad. Agr. Torino*, 1921, **65**: 53–64, 1923.

Waldron, Max: Effect of lightning on Citrus, *Fla. Grower*, **28**: (1) 5, 1923.

Watson, J. R.: Preserving fungus parasites of whitefly, *Fla. Agr. Exp. Sta. Press Bull.*, 217, 1913.

Insects of a Citrus grove, *Fla. Agr. Exp. Sta. Bull.*, 148. 167–267, 1918.

Webber, H. J.: The two freezes of 1894–1895 in Florida and what they teach, *U. S. Dept. of Agr., Yearbook*, 159–174, 1895.

Sooty mold of the orange and its treatment, *U. S. Dept. Agr. Div. Veg. Phys. and Path. Bull.*, 13. 34 *pp.*, 1897*a*.

Notes on orange diseases, *Fla. Hort. Soc. Proc.*, **10**: 1897, 69–73 1897*b*.

Letter on psorosis, *Fla. Hort. Soc. Proc.*, 1902, 48, 1902.

A comparative study of the Citrus industry of South Africa, *Union South Africa Bull.*, 6. 105 *pp.*, 18 *figs.*, 1925.

Webber, H. J. et al: A study of the effects of freezes on Citrus in California, *Calif. Agr. Exp. Sta. Bull.*, 304. 247–321, 1919.

Weber, G. F.: *Poria cocus* developed on tuckahoe found attached to orange tree root, *Abs. from Phytopathology*, **14**: 35, 1924.

Williams, F. L.: Segregating lemons affected with blossom end decline, *Calif. Citrogr*, **6**: 126–127, 1921.

Wilson, O. T.: Notes upon a market disease of limes, *Phytopathology*, **8**: 45–50, 5 *figs.*, 1918.

Winston, J. R.: Tear Stain of Citrus fruits, *U. S. Dept. Agr. Bull.*, 924. 12 *pp.*, 2 *pls.*, 1921.

Citrus scab, its cause and control, *U. S. Dept. Agr. Bull.*, 1118. 38 *pp.*, 16 *pls.*, 1923.

Winston, John R. and Bowman, John J.: Commercial control of Citrus Melanose, *U. S. Dept. Agr. Dept. Circ.*, 259. 8 *pp.*, 1923*a*.

Winston, J. R., Bowman, J. J. and Yothers, W. W.: Bordeaux-oil emulsion. *U. S. Dept. Agr. Dept. Bull.*, 1178. 22 *pp.*, 1923*b*.

Winston, J. R., Bowman, J. J. and Bach, W. J.: Relative susceptibility of some rutaceous plants to attack of Citrus scab fungus, *Journ. Agr. Research*, **30**: 1087–1093, 1925.

Winston, J. R. and Fulton, H. R.: The Field testing of copper spray coatings *U. S. Dept. Agr. Bull.*, 785. 9 *pp.*, 1919.

Winston, J. R., Fulton, H. R. and Bowman, J. J.: Commercial control of Citrus stem-end rot, *U. S. Dept. Agr., Dept. Circ.*, 293. 10 *pp.*, 1923.

Woglum, R. S.: Report of a trip to India and the orient in search of the natural enemies of the Citrus white fly, *U. S. Dept. Agr. Bur. Ent. Bull.*, 120. 58 *pp.*, 1913.

Fumigation of Citrus plants with hydrocyanic acid, conditions influencing injury, *U. S. Dept. Agr. Bull.*, 907. 43 *pp.*, 1920.

Seasonal helps on insect pest, control problems, *Calif. Citrogr*, **9**: 226, 227, 245, 1924.

WOLF, F. A.: Gummosis, *Plant World*, **15**: 60–66, 1912.
Citrus canker, *Journ. Agr. Research*, **6**: 69–99, 1916*a*.
Sclerotium rolfsii on Citrus, *Phytopathology*, **6**: 302, 1916*b*.
WOLF, F. A. AND MASSEY, A. B.: Citrus canker, *Ala. Agr. Exp. Sta. Circ.*, 27. 97–101, 1914.
WOODWORTH, C. W.: Orange and lemon rot, *Calif. Agr. Exp. Sta. Bull.*, 139. 12 *pp.*, 1902.

YOTHERS, W. W.: Spraying for the control of insects and mites attacking Citrus trees in Florida, *U. S. Dept. Agr. Farmers' Bull.*, 933. 38 *pp.*, 1918*a*.
Some reasons for spraying to control insect and mite enemies of Citrus trees in Florida, *U. S. Dept. Agr. Bull.*, 645. 19 *pp.*, 1918*b*.
Mixing emulsified mineral lubricating oils with deep-well waters and lime-sulphur solutions, *U. S. Dept. Agr. Bull.*, 1217. 6 *pp.*, 1924.

ZIMMERMAN, A.: Uber einige an tropischen Kulturpflanzen beobachtete, Pilze I, *Centrbl. f. Bakt.*, 2 Abt., **7**: 101–106; 139–147, 1901.

INDEX

Bold-face numbers indicate pages bearing illustrations, asterisks indicate pages opposite which there are colored illustrations.

A

Abnormalities on twigs and leaves, 322
Adustiosis. See Red blotch
Aegerita webberi on whiteflies, 265, 270, **271**
Aegle marmelos, mildew on, 256
Aeration of soil,
  in relation to disease, 74
  in relation to dry root rot, 109
African cherry orange (*Citropsis sp.*), 13
Age of fruit, related to decay, 526, 539, 541
Alabama, scab, 8, 486
Albedo browning, 443
Albino, in seed-beds, 65
Aleurothrixus howardii, 265
Aleyrodes. See Dialeurodes.
Alga spot, 261
  contributing conditions, 262
  control, 262
  method of attack, 262
  nature, 262
Algeria, melanose in, 226
Alkali injury,
  contributing conditions, **319**
  in Citrus orchards, 320
  prevention, 320
  symptoms, 318
  treatment, 320
Alternaria, 395
  citri,
    characteristics, 396
    distribution in California, 436
    in fruit drop, 435
    in fruit spot, 464
    in lemon decay, 538
    on oranges, 396
    related to splits, **518**
    spores, **396**
  fungus on leaves, 281
  rot,
Alternaria, rot,
    favored by endoxerosis, 425
    of lemons,
      causal agent, 391
      contributing conditions, 391
      control, 392
      distribution, **390**
      symptoms, 390
    of oranges, **395**
      causal agent, 394
      control, 396
      distribution, 393
      symptoms, 394
    related to picking, 532
  spots, **459**, 464
  with alkali injury, 318
  with chocolate spot, 277
"Ammoniated fruit." See Exanthema
Amylirosa aurantiorum, South America, 241
Anatomy of Citrus, 14
Ant, leaf-cutting, 333
Anthracnose,
  acervuli on leaves, **290**
  of lime,
    contributing conditions, 286
    control, 286, **461**
    distribution of, 283
    history, 283
    similar to scab, 494
    symptoms, 284, **285**, **461**
  of Satsuma, 293, 462
  rot, 396, **397**
  spot, **458**, **459**, **460**
    contributing conditions, 460
    control, 460
    distribution, 456
    similar to storage spot, 457
    symptoms, 457
  tear stain, 505
    contributing conditions, 456
    control, 456

- Anthracnose, tear stain,
    - distribution, 454
    - symptoms, **455**
  - withertip,
    - characteristics, 289
    - contributing conditions, 292
    - control, 292
    - distribution, 288
    - on leaves and twigs, 287, 290
- Aphids, on leaves, 330, **332**
- Argentina, diseases, 33
  - dodder, 342
  - lepra explosiva, 240
  - Rosellinia root disease, 98
  - scab, 487
- Arizona, black rot in, 394
- *Armillaria mellea*,
  - classification, 26
  - fans of mycelium, 91, **92, 93**
  - rhizomorphs, 90, **91, 92, 94**
  - root rot, 89
  - toadstools, **90, 91**
  - wood rot, 198
- Armillaria root rot. See *Armillaria mellea*
- *Aschersonia*
  - *aleyrodis*, on white flies, 265, 266, **267**
  - *coffeae*, 268
  - *eugeniae*, 268
  - *flavo-citrina* (*A. goldiana*), 268
  - *marginata*, 268
  - *pediculoides*, 268
  - *pisiformis*, 268
  - *sclerotiodes*, 268
  - *turbinata*, on wax scale, 268
- Ascomycetes, classification, 25
- *Aspergillus*
  - classification, 25, 27
  - *niger*, characteristics, **366**
  - rot, 365, 366
- Asphalt paint, 62
- *Atichia dominicana*
  - characteristics, **263**
  - on leaves, 262
- *Atta insularis*, leaf-cutting ant, 333
- Australia,
  - anthracnose spot, 457
  - Armillaria root rot, 89
  - black pit, 446
  - black rot, 394
  - black spot, 479
  - Botrytis rot, 385
- Australia,
  - Botrytis twig blight, 311
  - canker eradication, 213
  - diseases, 31
  - exanthema, 244
  - gummosis, 123
  - internal decline, 421
  - investigations, 5, 8
  - leaf blight, 275
  - melanose, 226
  - nematode, 113
  - Phytophthora rot, 379
  - scab, 486
  - Sclerotinia rot, 380
  - Septoria spots, 479
  - water injury, 112
- Australian desert lime (*Eremocitrus glauca*), 12
- Autobasidiomycetes, classification, 26
- Azores, gummosis, 122

B

- *Bacillus*
  - *citrimaculans*, 24, 450
  - *gummis*, Paraguay, 196
- Bacteria (Schizomycetes) nature, 20, 24
- Bacterial spot of So. Africa, **451**
  - causal agent, 452
  - contributing conditions, 453
  - control, 453
  - symptoms, 450
- *Bacterium*
  - *citriputeale*,
    - in black pit, 443
    - in blast, 297
  - *gummis*, 124
- Bark,
  - concave gum disease, 192
  - cross section of twig, **247**
  - decorticosis, 176, **177**
  - excresences in exanthema, 244, **246**
  - gummosis, 121
  - rot,
    - compared with other diseases, 174
    - distribution, 171
    - prevention, 171
    - susceptibility, 171
    - symptoms, 172, **173, 174, 175**
  - spot of Brazil, 193
- Basidiomycetes,
  - as wood rots, 197
  - classification, 26

Beetles,
  blue-green, Cuba, 119
  Fuller's Rose
    on leaves, 333
    on roots, 118
Bench rooting, in seed-beds, 65
Bibliography, 543
Bird-vine (mistletoe), Dendropemon, 342
Bitter sweet orange. See *Citrus aurantium*
Black,
  fungus, 270
  melanose, 229, 230
  pit,
    Bacterium citriputeale in, 443
    conditions favoring, 448
    control, 449
    distribution, 443
    susceptibility, 446
    symptoms, **440, 444, 445,** 446
  rot, in oranges, 393, **395**
  scale, Isaria fungus on, 265, 273
  scurf, 506
  spot, **479, 480**
  thrips on fruit, **508**
Blast. See Citro-necrosis
Bleaching powder, 56
Blemishes, miscellaneous, 520
Blight, Citrus, in Florida, 312, **313**
Blind pocket, 193
Blister rot, 353
Blossom blight (anthracnose), 283
Blossom-end decay, 421
Blotch, red, on fruit, 440
Blue and green molds, control, 360
Blue molds, 353, 357
  in picking, 531
Blue-contact mold, 357, **358**
  causal agent, 358
  compared with common green, 358
  contributing conditions, 359
  control, 360
  history, 359
  relation to picking, 531
  symptoms, 357
Blue-green beetles, on roots, Cuba, 119
Borax,
  treatment for molds, 361
  use against green mold, 55
Bordeaux mixture, preparation and use, 48
Bordeaux paste, preparation and use, 49
Bordeaux-oil emulsion,
  for melanose, 499
  preparation and use, 49
Borers, in wood decay, 200
Borneo, pink disease in, 304
Botryosphaeria, classification of, 26
Botryosphaeria ribis, characteristics, **414**
Botrytis cinerea,
    characteristics of, 386
    classification, 27
    factors favoring, 35
    fruiting on bark, 186
    in cold storage, 528
    in gummosis, 183, 185
    in lemon decay, 538
    in twig blight, 311
    inoculation, 185
    sclerotia, 186
    with frost injury, 202, 279
  damping-off, 64
  diseases in nursery, 68
  gummosis, 183, 184, 189
    causal agent, 185
    contributing conditions, 187
    control, 188, 189
    development, 185
    distribution, 183
    symptoms, 183
  rot, 387
    causal agent, 386
    conditions favoring, 386
    control, 388
    distribution, 385
    symptoms, 385
  vulgaris. See *B. cinerea*
Branches,
  canker on, 218
  diseases of, key to, 207
  S-shaped with exanthema, 248
  structure, 15
Brazil,
  Armillaria root disease, 98
  bark spot of, 193
  brown rot, 372
  diseases, 33
  exanthema, 244
  mal di gomma, 152
  melanose, 226
  nematode, 113
  scab, 487

Brazil,
  Septobasidium, 257, 259
  stem-end rot, 401
Bridge grafting after gummosis, **143**
Brown rot,
  causal agent, 374
  conditions favoring, 375
  control, 377
  effect of hot water, 376
  history, 372
  in washing, 532
  of lemons, 372, 374
  picking precautions, 532
  relation to moisture, 526
  spraying, 377
  symptoms, 373
Brown rot gummosis. See *Pythiacystis gummosis*
Brown spot,
  inherited type, 521, **523**
  of navel orange, **466*, 472**
    contributing conditions, 473
    control, 473
    symptoms, 473
Browning of albedo, 443
Buckskin on fruit, 505
Bud selection, relation to diseases, 69
Buds multiple, with exanthema, **246,** 248
Burgundy mixture, preparation and use, 50
Burns, chemical, **523,** 524

C

Cabuyao, 12
  See *Citrus hystrix*
Calamondin orange, 12
  See *Citrus mitis*
Calcium,
  carbonate, in chlorosis, 334
  relation to foliocellosis, 339
  with high potassium, 318
California,
  alkali injury, 318
  Alternaria,
    in fruit drop, 436
    rot of lemons, 390
    spot, 464
  anthracnose,
    rot, 396
    spots, 457, **458**
    tear stain, 455
  aphids, 333
California,
  Armillaria root rot, 89
  Aspergillus rot, 365
  black pit, 443
  black rot oranges, 393
  black scale, 265
  blind pocket, 193
  Botrytis, gummosis, 183
    rot, 385, **387**
    twig blight, 311
  brown rot of lemons, 372
  brown spot, **472**
  chlorosis, 334
  citro-necrosis (blast), 294
  citrus galls, 326
  concave gum, 192
  crinkley leaf, **329**
  Diplodia rot, 409
  diseases, 28
  dodder, 342
  Dothiorella gummosis, 191
  dry root rot, 105
  exanthema, 244, 249
  fumigation injury
    to fruit, 513
    to trunk, 155
  Fusarium rot, 398
  gummosis, 123, 124, 194
  internal decline, 421
  investigations, 6, 7, 8
  June drop, 435
  lichens, 260
  membranosis, 428
  mildew, 255, 256
  miscellaneous spots, 521
  mottle leaf (foliocellosis), 336
  nematode, 113
  peteca, 441
  Phomopsis stem-end rot, **402***
  Pleospora rot, 393
  Poria fungus, 109
  psorosis, 158
  red blotch, 440
  Rhizopus rot, 366
  Sclerotinia gummosis, 153
  Sclerotinia root rot, 105
  Sclerotinia rot, 380
  Sclerotinia twig blight, 310
  Septoria spots, 477
  shell bark, 176
  sour rot, 369, **371**
  stylar end rot, limes, 399, **400**

California,
  thrips injury, **507**
  Trichoderma rot, 364
  water injury, 112
  witches' broom, 327, **328**
  withertip (anthracnose), 288
Cameroons, pink disease in, 304
Cancrosis (Citrus canker). See Canker.
Canker (cancrosis), 212, **216*, 217**
  causal organism, 219
  environmental factors, 220
  eradication, 221, 222
  fumigation spots resembling, **514**
  geographical distribution, 212
  history, 212
  identification, 216
  investigation, 212
  on fruit and leaves, **216*, 482**
  on twigs, branches and roots, 218
  prevention, 221
  Pseudomonas citri in, **219**
  resistant host as carrier, 46
  spraying, 222
  spread by leaf miners, 333
  susceptibility of species and varieties, 43, 213
  symptoms, 215, **217,** 483
Capnodium citri,
  following white flies, 265
  sooty mold, 253, **254**
Carbolic acid, crude, 57
Carbolineums,
  analyses, 59
  caution in use, 60
  effect, 58
  experiments, 58
Carbon bisulfid, 58
Carpoptosis, 435
Cassytha vine, in Florida, 343
Caucasus, pink disease, 304
Cement, filling cavities, 200
Center rot (Alternaria rot), **390***
Cephaleuros mycoidea (*Mycoidea parasitica*)
  parasitic alga, 261
Cephalosporium lecanii, on insects, 272
Cercospora fumosa, on leaves Italy, 281
Cercospora spots, on leaves, 281
Ceroplastes (wax scale), Aschersonia on, 268
Ceylon,
  canker, 213
  fungus on insects, 268
  mildew, 255, 256
  mistletoe, 341
  pink disease, 304
Chætospermum glutinosa, 12
Charcoal rot of limes, 414
Chemical burning, 524
Chemical stimuli, to gum formation, 196
Cherry orange (*Citropsis sp.*), 13
China,
  anthracnose stain, 454
  bark rot, 171
  black spot, 479
  canker, 213
  diseases, 31
  greasy spot, 229
  inspissosis, 415
  investigations, 8
  leprosis, 231
  melanose, 226
  mistletoe, 341
  psorosis, 158
  scab, 486
  witches' broom, 327
Chloride of lime (chlorinated), 56
Chlorosis, 334. See Mottle leaf.
Chocolate spot, in Egypt, 276, **277**
Cinnamon fungus (*Verticillium heterocladum*) on insects, 272
Citrange, scab on, 494
Citro-necrosis,
  black pit form,
    Bacterium citriputeale in, 443
    conditions favoring, 448
    control, 449
    distribution, 443
    susceptibility, 446
    symptoms, 440, 444, 445, 446
  blast form of, 293, **294, 295, 296**
    causal agent, 297
    conditions favoring, 297
    control, 302
    development, 294
    distribution, 293
    history, 293
    on leaves and twigs, 294
    section through lesion, 296
    susceptibility, 302
Citron. See *Citrus medica*
Citropsis (African cherry orange), 13

Citrus aurantifolia (lime),
  anthracnose, 283, **461**
  blast, 302
  canker, 213
  charcoal rot, 414
  Diplodia gummosis, 190
  Diplodia rot, 409
  mal di gomma, 152
  Pythiacystis gummosis, 138
  Rosellinia root rot, 98
  Sphaeropsis knot, 322
  susceptibility to disease, 11
  stylar-end rot, 399, 400
Citrus aurantium (sour orange),
  blast, 302
  canker, 221
  dry root rot, 108
  inspissosis, 416
  mal di gomma, 151
  Pythiacystis gummosis, 137
  Rosellinia root disease, 98
  scab, **223,** 494
  susceptibility to disease, 10
Citrus blast. See Citro-necrosis
Citrus blight, in Florida, 312, **313,** 314
Citrus canker. See Canker
Citrus galls, **326**
Citrus hystrix (papeda), 12
  bark rot, 172
  resistant to canker, 221
  scab, 494
Citrus limonia (lemon)
  albedo browning, 443
  alternaria rot, 389
  anthracnose (withertip), 287
  anthracnose spot, **458**
  Armillaria root rot, **93**
  bacterial spot, **451**
  black pit, **444**
  black spot, 480
  blast, 302
  Botrytis gummosis, 183
  Botrytis rot, 385
  canker, 213
  crinkley leaf, 329
  Diplodia gummosis, 190
  Diplodia rot, 409
  Dothiorella gummosis, 191
  dry root rot, **106**
  frost injury to fruits, **433**
  fumigation injury, **513**
  Fusarium rot, 399
Citrus limonia (lemon)
  hollow core, **427**
  internal decline (endoxerosis), 421
  leprosis, 237
  mal di gomma, 151
  membranosis, 428
  mildew, 256
  oleocellosis, **466***, **467**
  peteca, 441
  pink mold, 363
  problems of decay, 529
  Pythiacystis gummosis, 127
  red blotch, 440
  rust mite, 504
  scab, 494
  Sclerotinia gummosis, 154
  Sclerotinia root rot, 105
  Septoria spots, 477, **478**
  shell bark, 176
  sour rot, 370, **371**
  susceptibility to disease, 10
  tear stain, 454
  witches broom, **328**
Citrus maxima (grapefruit),
  anthracnose (withertip), 287
  anthracnose spots, 457
  black pit, **445,** 448
  blast, 302
  canker, 213
  cold storage spots, 474
  Diplodia rot, 409
  greasy spot, 230
  mal di gomma, 151
  origin, 44
  Phomopsis stem-end rot, 401
  psorosis, 165
  Pythiacystis gummosis, 137
  rust mite, 505
  scab, 494
  susceptibility to disease, 11
  thrips injury, 508
  Ustulina, 112
  witches' broom, **328**
Citrus medica (citron), 11
  blast, 302
  canker, 214
  mal di gomma, 152
  Pythiacystis gummosis, 138
  Rosellinia root disease, 98
Citrus mitis (calamondin orange), 12
  bark rot, 172
  greasy spot, 229

Citrus mitis (calamondin orange),
  inspissosis, 416, **418**
  mal di gomma, 152
  resistant to canker, 214, 221
  scab, 494
Citrus nobilis (king orange), 11, 12
  black pit, 446
  scab, 494
Citrus nobilis var *deliciosa* (mandarin), 11
  anthracnose, 288
  anthracnose rot, 396
  anthracnose spots, 457
  bacterial spot, **451**
  bark rot, 172
  black pit, 446
  black spot, **480**
  blast, 302
  canker, 214
  Cytosporina spot, 465
  exobasidium fungus, 503
  greasy spot, 229
  hesperidin in, 431
  inspissosis, 416
  mildew, 256
  Phytophthora rot, 380
  Psorosis, 165
  scab, 494
  Septoria spots, 477
Citrus nobilis var *unshiu* (Satsuma orange), 12
  anthracnose of fruit, 462, **466***
  bark rot, 172
  black pit, 448
  blast, 302
  canker, 214
  inspissosis, 416
  scab, 494
Citrus nematode, 113, **115**
Citrus scab (verrucosis), 485
Citrus sinensis (sweet orange), anthracnose, 287
  anthracnose rot, **397**
  anthracnose spot, **458, 459**
  Armillaria root rot, **92**
  bark spot Brazil, 193
  black pit, **445**
  black rot, 393
  black spot, 480
  blast, 302
  blind pocket, 193
  Botrytis rot, **387**
  brown spot, **472**
Citrus sinensis (sweet orange), canker, 213
  cold storage spots, 474, **475**
  concave gum, 192
  Diplodia gummosis, 190
  Diplodia rot, 409
  dry root rot, **107,** 108
  frost injury to fruit, **430, 432**
  fumigation injury, **514**
  Fusarium rot, 399
  hesperidin in, **431**
  inspissosis, 416
  juice-sack granulation, 426
  leprosis or nail head rust, 231, 237
  mal di gomma, 151
  mildew, 256
  oleocellosis, **469**
  origin, 44
  Phomopsis stem-end rot, 401
  Phytophthora rot, 380
  psorosis, 158, 165
  Pythiacystis gummosis, 126, 131, 137
  Rosellinia root disease, 98
  rust mite, 504
  scab, 494
  Sclerotinia gummosis, 154
  sour rot, 370
  susceptibility to disease, 9
  tear stain, **455**
  water injury, 110
  withertip of, 287
Citrus trifoliata (Poncirus), scab, 494
Citrus yusu, resistant to canker, 214
Cladosporium
  citri, (*Spaceloma fawcettii*), 490
  herbarum, 237
  herbarum var *citricolum*, characteristics of, 237
Classes of Citrus diseases, 18
Classification of fungi, 22
Claucena lansium, scab on, 493
Cold storage,
  relation to decay, 528
  spots, 474
Collar rot (mal di gomma), 146, **151**
Colletotrichum glœosporioides, following lightning, 317
  acervuli, **460**
  characteristics, 289, **290**
  in anthracnose rot, 396
  in fruit drop, 435
  in tear stain, 454

Colletotrichum glœosporioides
  secondary agent in leprosis, 236
  tear stain fungus, 505
  variability, **291**
  with alkali injury, 318
Colletotrichum spots, 454
Colloidal copper, 51
Colloidal sulfur, 54
Colored illustrations
  127*, **163***, **216***, **294***, **304***, **358***, **372***, **390***, **402***, **410***, **422***, **440***, **466***, **486***, **496***
Common green mold, 353, **358***
  causal agent, 355
  compared with blue-contact, 358
  contributing conditions, 356
  control, 357
  relation to picking, 531
  symptoms, 353
Concave gum disease, 192
Coniothecium chomatosporum with black scurf, 506
Coniothecium scabrum with black scurf, 506
Copper,
  carbonate, preparation and use, 51
  compounds, 48
  sulphate (blue stone)
    in washing, 533
    stimulus to gum formation, **195,** 196
    use of, 50
Coprinus atramentarius on roots, 198
Corticium
  koleroga in thread blight, 314
  salmonicolor in pink disease, **306**
Corrosive sublimate, dilution for use, 54
Costa Rica, psorosis, 158
Cottony rot, **372***, **380,** 381
  contributing conditions, 382
  control, 384
  development, 382
  history, 383
  symptoms, 380
Cover crops,
  relation to cottony rot, 385
  relation to diseases, 77
Creasing of fruit, 520
Creosote, 57
Cresol, in liquor cresolis compositus, 61
Crinkly leaf, on lemon, **329**
Crown roots, diseases, 121
Crude carbolic acid, 57
Crystallization (granulation), 426
  relation to frost, 434
Crystals, hesperidin, 431
Cuba
  black rot, 394
  blue-green beetles, 119
  Diplodia gummosis, 190
  Diplodia rot, 409
  Diplodia twig blight, 308
  diseases, 29
  exanthema, 244
  greasy spot, 229
  investigations, 7
  leaf-cutting ant, 333
  Phomopsis stem-end rot, 402
  psorosis, 158
  Rhizopus rot, 366
  Rolf's sclerotium rot, 367
  Septobasidium, 257
  shell bark, 177
  Sphaeropsis knot, 322
  stylar end rot, limes, 399
  thrips injury, 508
Cultivation, relation to disease, 75
Cultural operations, related to disease, 64
Curing lemons, relation to decay, 533
Cuscuta (dodder), 342
  in nursery, **70**
  in seed bed, 65
Cyanide of mercury, 55
Cytosporina citriperda, characteristics, 465
Cytosporina spot, on mandarin orange, 465

D

Damping-off, 64
Decay in fruits, 525
  cold storage, 528
  conditions influencing, 525
    curing, 533, 534
    drying, 526
    environmental effects, 525
    grading, 527, 535
    packing, 527, 536
    picking, 526, 531
    problems, 525
    storage, 528, 534, 539
    sweating, 533
    transit, 527, 536
    washing, 526, 532

Decay in lemons
  causes, 541
  problems, 529
Decline, internal of lemon, 421
Decorticosis. See Shell bark
Dendropemon
  bicolor, mistletoe, West Indies, 342
  carbiaeum, mistletoe, West Indies, 342
Deterioration,
  in fruits, 525
  of lemons, 529
Dialeurodes
  citri (white fly), 265
  citrifolii (white fly), 265
    yellow aschersonia on, 268
Diaporthe, perfect stage of Phomopsis, 405
Didymella citri, with bark spot, 193
Dieback (exanthema)
  control, 249, 501
  marking on fruit, **294***, **496***, 500
  on twigs, **245, 246, 247, 294***
  See also Exanthema
Diplodia
  classification, 27
  following lightning, 317
  gummosis,
    contributing conditions, 190, 191
    control, 191
    distribution, 190
    history, 190
    symptoms, 190
  in dieback, West Indies, 309
  in frost injury, 202, 279
  in heart rot, 198
  natalensis
    causal agent, **410**
    characteristics, 411
    contributing conditions, 411
    control, 411
    distribution, 409
    in gummosis, 124, 190
    in stem-end rot, 409
    in twig blight, 308
    on Florida limes, 415
    on lime roots, 120
    on twigs, 236
    symptoms, 409, **410***
  rot. See *D. natalensis*
Diplodia twig blight,
  control, 309
  symptoms, 308
Discomycetes, classification, 25
Disease, definition, 1
Diseases,
  aeration of soil in relation, 74
  bud selection in relation, 69
  budding and grafting in relation, 71
  classes and types, 18
  conditions affecting, 34
  cover crops in relation, 77
  cultivation in relation, 75
  cultural operations, in relation, 64
  dead spot, 274
  environmental factors, 35
  eruptive, 212
  exclusion, 44
  fertilizing in relation, 76
  geographical distribution, 28
  history of investigations, 5
  in seedbed, 64
  investigations, 5
  irrigation in relation, 73
  of branches, twigs and leaves, 207
  of crown roots and base of trunk, 121
  of fruit, 347
  of nursery, 65
  of root and trunk, 83
  of trunk and main branches, 158
  planting in relation, 71
  prevention and treatment, 47
  principles of treatment, 39
  pruning in relation, 78
  quarantine measures against, 46
  resulting in death of entire parts, 283
  scaly bark in California, 158
  susceptibility, 9, 10, 12, 43
Disinfectants,
  Citrus, 48
  miscellaneous, 54
  on canker, 220
Disinfection of cuts, 41
Dodder. See Cuscuta
Dothiorella
  gummosis, 191
  ribis
    characteristics, **413, 414**
    in gummosis, 191
    in stem-end rot, 413
  rot, **410***, 412
    causal agent, 413
    control, 414
    symptoms, 413
Drop of fruit, 435

Dry rot of roots, 106
Dry rot of fruit (inspissosis), 415, **416, 418**
  causal agent, 419
  contributing conditions, 420
  distribution, 415
  insect transmission, 420
  prevention, 420
  symptoms, 417
Dry tip. See Internal decline
Drying fruit, in relation to decay, 526

E

Egypt,
  chocolate spot, 277
  diseases, 30
  gummosis, 127
  melanose, 226
Empusa, classification, 25
Emulsified cresol, 61
Emulsions, oil with sulfur, 53
Endoxerosis. See Internal decline
Entomogenous fungi, 264, 266
Entomophthora, classification, 25
Entomophthora fumosa, on mealy bug, 272
Environmental factors,
  in canker, 220
  in decay, 525
Eremocitrus glauca, (Australian desert lime), 12
Eruptive diseases, 212
Ethelene gas, curing fruit, 534
Eumycetes (true fungi), 23
Eureka lemon, decorticosis of, 176
Exanthema,
  contributing conditions, 249
  control, 249
  distribution, 244
  on fruit, **294*, 496*, 502**
  on twigs, 243, **245, 246, 247, 294***
  soil favoring, 249
  symptoms, 244, **245, 246**
  theories as to cause, 248
Exobasidium citri,
  characteristics of, 503
  on fruit, Russia, 503

F

Fertilizing, relation to diseases, 76
Fire ant (*Solonapsis gemmenata*), 196
Florida
  anthracnose of lime, 283
  anthracnose spots, 457
  anthracnose stain, 454
  aphids, 333
  black rot, 394
  brown rot, 373
  canker eradication, 212
  Cassytha vine, 343
  charcoal rot, limes, 414
  Diplodia gummosis, 190
  Diplodia rot, 409
  Diplodia twig blight, 308
  diseases, 29
  dodder (Cuscuta), 342
  exanthema, 244, 249
  flyspeck fungus, 500
  frenching (foliocellosis), 336
  fruit drop, 435
  fungi on insects, 268
  Fusarium rot, 398
  greasy spot, 229
  gummosis, 123, 194
  investigations, 6
  lichens, 201, 260
  melanose, 226
  nematode, 113
  Phomopsis stem-end rot, 401
  psorosis, 158
  rust mite injury, 503
  scab in, 486
  Septobasidium fungus, 257, 259
  shell bark, 177
  Sphaeropsis knot, 322
  stylar-end rot, limes, 399
  thrips injury, 506
  water injury, 110
  whiteflies, 265
  withertip (anthracnose), 288
Flyspeck fungus on fruit, **500**
Foliocellosis. See Mottle leaf
Foot rot (mal di gomma), 146, **151**
Formaldehyde (40 per cent formalin), 57
Formalin (40 per cent formaldehyde) dilution for use, 57
Formosa,
  canker, 213
  fungi on insects, 268
  pink disease in, 304
  Septobasidium fungus, 257, 259
Fortunella (meiwa kumquat), 12
  crassifolia, resistant to canker, 214

Fortunella
  hindsii,
    Hongkong wild kumquat, 12
    susceptible to canker, 214
  japonica (round kumquat), 12
    resistant to canker, 214
  margarita (oval kumquat), 12
    resistant to canker, 214
    scab on, 494
Frenching (foliocellosis). See Mottle leaf
Frost injury
  oil spotting, **430**
  protection against, 434
  relation to fruit decay, 526, 541
  resistance of species, 202
  secondary effects, 202
  symptoms, 201
  to fruit, 429, **430, 432, 433**
  to leaves, 277, **278**
  to twigs, 277
  treatment, 202
  with *Botrytis cinerea*, 202
Frost protection, relation to disease, 76
Frosted fruit, separation, 434
Frosted trees, rebuilding, 203
Fruit,
  drop
    as related to *Alternaria citri*, 435
    control, 438
    history, 435
    June, 436
  gumming, 439
  identification key to diseases, 347
  rots, 353
  spots, diagnosis of, 530
Fruit structure, 17
Fuller's rose beetle,
  injury to leaves, 333
  injury to roots, 118
Fumigation injury,
  on fruit, **513, 514**
  to leaves, 279
  to roots and trunk, 155, **156**
Fungi,
  classification, 22
  definition, 19
  life of, 21
  minute structure, 20
  nature, 19
  on white flies, 265
  parasitic on insects, 266
Fungi spores, 22
  imperfecti, classification, 26
Fungicides,
  for Citrus, 48
  miscellaneous, 54
Fungus
  parasites, on scale insects, 264
  root rot (*Armillaria mellea*), 89
Fusarium,
  after fumigation injury, **155**
  associated with Pythiacystis, 138
  in damping-off, 64
  in dry root rot, 108
Fusarium
  aleyrodis,
    on insects, 270
    on whiteflies, 265
  epicoccum, on insects, 270
  lateritium, in rot of fruit, 399
  limoni, 124
  solani, in fruit rot, 399
Fusarium rot, on fruit, 398

G

Galls, Citrus, **326**
Ganoderma fungus, on dead wood, 198
Gas injury to roots, 120
Geographical distribution of diseases, 28
Glœosporium foliicolum,
    characteristics, **463**
    in anthracnose, 462
    on leaves, 293
  limetticolum,
    characteristics of, 284, **286**
    in anthracnose of lime, 283
    in fruit drop, 435
    on lime fruits, **461**
    spots, 454
Glomerella, classification of, 26
Gopher injury, 154
Grading fruit, relation to decay, 527, 535
Grafting,
  formulae for wax, 62
  relation to diseases, 71
Granulation, in juice sacks, 426
Grapefruit. See *Citrus maxima* var *uvacarpa*
Gray fungus (*Botrytis cinerea*) in gummosis, 185, **186**
Gray mold (Botrytis rot), 385
Greasy spot, 229, 230

- Green mold (*Penicillium digitatum*), 353, **358***
- Green spot on fruit, **466, 467, 469**
- Guam,
  - anthracnose stain, 454
  - psorosis, 158
- Guinea, Dutch, exanthema, 244
- Gum,
  - diseases,
    - concave, 192
    - early investigations, 124
    - geographical distribution, 123
    - historical review, 122
  - formation,
    - due to fire ant, 196
    - factors influencing, 121
    - in fruit, 439, 515
    - in ring blotch, 243
    - in twig gumming, 315
    - miscellaneous causes, 194
    - with endoxerosis, 422, **423,** 424
    - with fumigation injury, **156**
  - in exanthema, 244, 247
  - pockets, 191
  - spot, 252
- Gum-like substance,
  - in blind pocket, 193
  - in melanose, 228
  - in wood rots, 196
- Gummosis,
  - chemical stimuli, 196
  - control, 145
  - due to
    - Botrytis, 183, 184, 189
    - Diplodia, 190
    - Dothiorella, 191
    - Pythiacystis, 125
    - rodent injury, 154
    - Sclerotinia, 153
  - Fusarium with, 138
  - in relation to
    - bark diseases, 121
    - injuries, 135
    - moisture, 136
    - nursery, 67
    - temperature, 136
  - prevention, 139
  - resistance of sour orange, 137
  - susceptibility of sweet oranges, 137
  - treatment, 141
  - types, 194

H

- Hail injury, **466***
- Hawaiian Islands,
  - anthracnose of lime, 284
  - anthracnose stain, 454
  - brown rot, 373
  - canker, 213
  - exanthema, 244
- Heart rots, 196, **197, 199**
  - causal agents, 197
  - contributing conditions, 196
  - control, 198
- Heat, effects on fruit, 524
- Hesperidin crystals, with frost injury, 431
- History of disease investigations, 5
- Hollow core in lemons, 426, **427**
- Honey fungus (*Armillaria mellea*), 89
- Honeydew, sooty mold on, 253
- Hormodendron fungus, stage of Cladosporium, 236
- Hyaline rot in Japan, 388
- Hybrids,
  - canker on, 13, 214
  - scab on, 13
- Hydnum fungus on dead wood, 198
- Hyphomycetes, classification, 27
- *Hypocrea rufa*, 365
- *Hypocrella*
  - *javonica* on red scale, 268
  - *reineckiana*, on insects, 268

I

- Iceing fruit, relation to decay, 527
- Identification key,
  - fruit diseases, 347
  - root and trunk diseases, 84
  - twig and leaf diseases, 205
- Inarching, after gummosis, **143**
- India,
  - canker in, 213
  - diseases, 33
  - mildew in, 255
  - pink disease in, 304
  - Ustilina fungus, 112
- Indo China, canker in, 213
- Insect effects,
  - on leaves, 330
  - injury to roots, 118
- Insects, scale, 263
- Inspissosis. See Dry rot of fruit
- Internal breakdown, membranous stain, 428

Internal decline, (endoxerosis), 421, **422***, **424**
  conditions favoring, 424
  control, 425
  distribution, 421
  of lemons, 422
  related to picking, 532
  symptoms, **422***
Iron, relation to chlorosis, 334
Irrigation,
  alkali injury, 74
  Armillaria root rot, 74
  internal decline, 74
  relation to mal di gomma, 73
  relation to Pythiacystis gummosis, 73
Isaria fungus, on black scale, 265, 273
Isle of Pines, Phomopsis stem-end rot, 402
Italy,
  Armillaria root rot, 89
  black pit (mal secco), 446
  Botrytis rot, 385
  brown rot, 373
  Cercospora spots, 281
  citro-necrosis (blast), 294
  Citrus galls, 327
  Cytosporina spot, 465
  exanthema, 244
  gummosis, 123, 127
  investigations, 5, 7
  membranosis, 428
  peteca, 441
  Phomopsis, stem-end rot, 404
  Septoria spots, 477
  witches broom, 327

J

Jamaica, Sphaeropsis knot, 322
Japan,
  anthracnose of Satsuma, 293, 462
  anthracnose stain, 454
  bark rot, 171
  canker, 213, 215
  diseases, 32
  greasy spot, 229
  hyaline rot, 388
  inspissosis, 416
  investigations in, 8
  melanose, 226
  Phyllosticta leaf spot, 274
  psorosis, 158
  scab (verrucosis), 486
Java,
  anthracnose stain, 454
  canker, 213
  greasy spot, 229
  knot, 322, **324**
  mildew, 255, 256
  mistletoe, 341
  pink disease, 304
Javanese Hypocrella, on red scale, 268
Juice-sack granulation, 426
June drop of fruit, 436

K

Key,
  identification, fruit diseases, 347
  root and trunk diseases, 84
  twig and leaf diseases, 207
King orange. See *Citrus nobilis*
Knot, Sphaeropsis, 322, **323**
Kumquats. See *Fortunella.*

L

Leaf
  blight, due to Phytopthora, 275, 380
  cutting ant, 333
  miner, 333
  spot,
    Cercospora, 281
    miscellaneous, 279
    Phyllosticta, 274, **486***
Leaves,
  abnormal, 248
  canker, 215, **216, 217**
  gum spot, **251,** 252
  key to diseases, 207
  ring blotch, 243
  scab, 222
  structure, 16
Lecanium
  hesperidum, Verticillium on, 272
  scales, fungi on, 268
  viride, Cephalosporium on, 272
Lemon. See *Citrus limonia.*
Lemon fruit,
  handling, 529
  internal decline, 421
  picking, 531
  problems of decay, 529
Lemon Men's Club
  brown rot investigation, 372
Lepra explosiva, symptoms, 240
Leprosis, **163***, 231, **233, 234**, 240, **484**, See nailhead rust.

Leptothyrium pomi, flyspeck fungus, **500**
Lichens,
  control, 201, 261
  on leaves, **260**
  on trunk, 200
Lightning injury, 315, **316,** 317
Lime. See *Citrus aurantifolia*
Lime-sulfur,
  dilution table, 53
  oil emulsions, 53
  paste and washes, 54
  preparation and use, 52
Liquor cresolis compositus U. S. P., dilution for use, 61
Lisea parlatoriae on insects, 270
Loading fruit, relation to decay, 536
Loranthaceae, mistletoe, 341
Loranthus
  calcyculatus, in Yucatan, 341
  parasiticus, in China, 341
  philippensis, in Orient, 341
Love vine (Cuscuta), 342

M

Macrosporium fungus, on leaves, 281
Magnesium, relation to chlorosis, **335**
Mal di gomma, 146, **151, 152,** 153
  accompanying dry root rot, 105
  causal agent, 148
  contributing conditions, 150
  control, 152
  distribution, **146**
  history, 122, 146
  in nursery, 68
  susceptibility, 150
  symptoms, 147
Mal secco (blast and black pit) in Italy, 302, 446
Malay States, canker, 213
Mandarin orange
  See *Citrus nobilis* var *deliciosa*
Markets, decay in, 537, 539
Mauritius, canker, 213
Mealy bug, Entomophthora fungus on, 272
Mechanical forces, influencing diseases, 35
Mechanical injury, scurf from, **511**
Mediterranean countries, diseases, 29
Melanconiales, classification, 27
Melanose
  causal agents, 228
  conditions favoring, 228
Melanose
  control, 229
  development, 227
  distribution, 226
  fungus (*Phomopsis citri*), 497
  history, 226
  on fruit, **496*, 498**
  prevention, 499
  spots, 228
  symptoms, on fruit, 227, **496*, 498**
  tear streaking from, 506
Membranosis, 428, **440***
Membranous stain, 428, **440***
Mercuric chloride, use of, 54
Mercuric cyanide, dilution for use, 55
Mexico,
  dodder (Cuscuta), 342
  melanose, 226
  psorosis, 158
Microcera
  Fujikuroi, on insects, 269
  fungus on insects, 270
  rectispora, on insects, 270
Mildew,
  contributing conditions, 257
  prevention, 257
  symptoms, **255**
Mistletoes, Loranthaceae, 341
Moisture,
  effect on decay, 526
  influence on blast, 37
Mold,
  blue-contact, 357, **358***
  common green, 353, **358***
  gray (Botrytis rot), 385
Moniliales, classification, 27
Moss, (lichens),
  on leaves and twigs, 260
  on trunk, 200
Mottle leaf (foliocellosis), 336, **337, 338**
  contributing condition, 339
  related to calcium, 340
  remedial measures, 340
  symptoms, 338
  with exanthema, 248
Multiple buds, in exanthema, **246,** 248
Mushroom root rot, (*Armillaria mellea*), 89, **90, 91–94**
Mycelium sterile, 27
Mycoidea parasitica (alga), 261
Mycrosphærella
  lageniformis on leaves, California, 281

Mycrosphaerella loefgrini, on leaves, Brazil, 281
Myriangium duriaei, on insects, 265, 270
Myxomycetes (slime molds), 24

N

Nailhead rust (leprosis), **163*, 233, 234, 484**
  age of tissue affected, 237
  causal agents, 236
  climatic conditions, 238
  compared to psorosis, 235
  control, 238
  development, 235
  distribution, 231, **232**
  fungus in diseased tissue, 236
  history, 231
  on fruit, 483, **484**
  susceptibility of species, 237
  symptoms, 234
Navel orange, structure, 394
Necrosis, black pit form, 443
Nectria
  barbata, on insects, 270
  diploa
  on insects, 269
  tuberculariæ, on insects, 270
Nematode worm,
  characteristics, **115**, 116
  control, 117
  distribution in soil, 116
  effects, 113, **114**
  on roots, 113, **115**
Nematospora fungus,
  characteristics, **419**
  classification, 25
  in dry rot of fruit, 415, **419**
New Zealand,
  Botrytis twig blight, 311
  melanose, 226
Nutrition, relation to June drop, 438

O

Oak root fungus (*Armillaria mellea*), 89
Oidium tingitaninum, in powdery mildew, 255, **256**, 257
Oil,
  emulsions,
    Bordeaux, 49
    sulfur, 53
Oil,
  lemon,
    experiments, 468
    injury, 120
  spot (oleocellosis), 466*
    picking, 531
    related to washing, 532
Oleocellosis (oil spot), **466*, 467, 469**
  contributing conditions, 470
  control, 471
  experiments, 468
  history, 466
  symptoms, 467
  with frost injury, 430
Olive-green mold, 353, **358***
Oomycetes, classification, 24
Oöspora Citri-aurantii, **371**
  causal agent, 370
  characteristics, **370**
  classification, 27
  contributing conditions, 370
  control, 372
  in lemon decay, 538
  rot, symptoms, 369, 371, 372
Oosporoidea, 370
Ophionectria coccicola, **269**. See Podonectria.
Ophionectria tetraspora, 270
Oranges,
  handling, 525
  problems of decay, 525
  sour. See *Citrus aurantium*
  sweet. See *Citrus sinensis*
Orchard sanitation, 40
Orient, diseases in, 45

P

Packing fruit, relation to decay, 527, 536
Paint,
  asphalt, 62
  white lead, 62
Palestine, diseases, 30
  nematode in, 113
Papeda, 12. See also *Citrus hystix*.
Paradiplodia aurantiorum, in lepra explosiva, 241
Paraguay,
  diseases, 33
  gummosis, 196
  lepra explosiva, 240
  scab, 487

- Parasitic flowering plants, 341
- Parlatoria scales, fungi on, 268
- *Pellicularia koleroga,* in thread blight, 314
- *Penicillium,*
  - classification, 25, 27
  - *digitatum* (green mold)
    - borax treatment, 361
    - characteristics of, **354, 355**
    - control, 357
    - in lemon decay, 538
    - in picking, 531
    - white mutation, 355
  - *italicum* (blue-contact mold), 357, **358***
    - in lemon decay, 538
  - *roseum* (pink mold), characteristics of, **363**
    - inoculations with, 363
  - *stoloniferum*, 355
- Permanganate of potash, dilution, 55
- Persian limes, stylar-end rot of, 399
- Peteca,
  - cold storage, 528
  - control, 443
  - symptoms, **440***, 441, **442**
- Philippines,
  - anthracnose stain, 454
  - bark rot, 171
  - canker, 213
  - Diplodia rot, 409
  - diseases, 33
  - exanthema, 244
  - greasy spot, 229
  - inspissosis, 415
  - investigation, 8
  - leprosis, 231
  - mal di gomma, 152
  - mistletoe, 341
  - pink disease, 304
  - psorosis, 158
  - witches broom, 327, **328**
- *Phoma*
  - *citricarpa,*
    - characteristics, **481**
    - classification, 27
  - *omnivora*, in Australia, 112
- Phoma-like fungus, in concave gum, 192
- *Phomopsis*
  - *californica,*
- *Phomopsis, californica,*
    - characteristics, 406, **407**
    - culture, **407**
    - inducing shell bark, 180
  - *caribaea*, 403
    - characteristics, **406**
  - *citri,*
    - as cause of melanose, 228
    - characteristics, 404, **406, 407**
    - cultures, 407
    - distribution, 401
    - effect on twigs, 228
    - in fruit drop, 435
    - in melanose, 226, 497
    - in stem-end rot, 401
    - on dead twigs, 236
    - pycnidia on fruit, **405**
  - classification, 27
  - *cytosporella,*
    - characteristics, 407
  - following lightning, 317
  - stem end rot, 401, 402*, 403
- Phycomycetes, classification, 24
- *Phyllosticta,*
  - *citricola*, on leaf, 274
  - *curvarispora*, 274
  - leaf spot, 274
- Physalospora,
  - classification, 26
  - perfect stage of Diplodia, 411
- Physiological decline, 421
- Physiology of Citrus, 13
- *Phytomonas citri* (*Pseudomonas citri*) **219**
- *Phytomonas citriputeale.* See *Pseudomonas citriputeale*
- Phytophthora,
  - in damping off, 64
  - leaf blight, 275
- *Phytophthora* rot, 379
  - *citropthora.* See *Pythiacystis citrophthora*
  - *hibernalis*, 379
  - *parasitica,*
    - characteristics, **148, 149**
    - classification, 25
    - in leaf blight, 275, 380
    - in mal di gomma, 146
    - similar to Pythiacystis, 135
    - temperature influence, 35
    - temperature range, 150

Phytophthora terrestris. See *P. parasitica*
Picking fruit, relation to decay, 526, 531
Pinhole decay (blue-contact mold), 357
Pink disease (rubellosis),
  causal agent, 306
  conditions favoring, 307
  Corticium salmonicolor, **306**
  distribution, **304**
  history, 304
  prevention, 307
  symptoms, **304***, 305
Pink mold, due to *Penicillium roseum*, 362, **363**
Plectomycetes, classification, 25
Pleospora,
  classification, 26
  disrupta, on leaves South Africa, 282
  on leaves, 281
  rot, **390***, 393
Pocket gum, 192
Podonectria
  aurantii on insects, 270
  coccicola on insects, 265, **269**
  echinata, on insects, 270
Polyporus, as wood rot, 198
Polystictus
  classification of, 26
  versicolor, as wood rot, **197**, 198, **199**
Poncirus trifoliata (trifoliate orange), 12
  canker on, 213
  mal di gomma, 151
  scab, 494
Poria
  cocus, on roots, 109
  vaporiora, on roots, 109, 198
Porto Rico,
  black spots of grapefruit, 523
  Diplodia rot, 409
  exanthema, 244
  Fusarium rot, 398
  mistletoes, 342
  Phomopsis stem-end rot, 401
  pink disease, 304
  psorosis, 158
  Rhizopus rot, 367
  water injury, 112
Potassium,
  high concentration, 318
  permanganate, 55
Powdery mildew, 255
  causal agent, 256
Powdery mildew,
  contributing conditions, 257
  hosts, 255
  prevention, 257
Pox (cold storage spot), 474, 528
Precooling fruit, relation to decay, 528
Proprietary remedies, 61
Protobasidromycetes, 26
Pruning,
  for melanose, 499
  in relation to disease, 78
Pseudhaplosporella aurantiorium, in lepra explosiva, 240
Pseudococcus citri (mealy bug) Entomophthora on, 272
Pseudomonas citri. See Canker
Pseudomonas citriputeale,
  cause of black pit, 443
  cause of blast, 293
Psorosis (California scaly bark), 158, **160**, **162**, **163***, **168**
  contributing conditions, 164
  control, 167, **168**, **169**
  development, 163
  distribution, 158, **159**
  history, 158
  susceptibility, 43, 165
  symptoms, 159, **160**, **162**
  treatment, 165
Psylla, on leaves, Africa, 333
Puffing of fruit, 520
Pummelo, canker on, 214. See also *Citrus maxima*
Pyrenomycetes, classification, 25
Pythiacystis,
  in damping off, 64
  similar to Phytophthora, 135
Pythiacystis citrophthora,
  characteristics, **133**, **134**, 374
  classification, 25
  in brown rot, 372
  in gummosis, 125
  influence of temperature, 36, 150
  inoculation with, 132
  isolation, 133
  on lemon rind, **373**
  related to moisture, 526
  similar to Phytophthora, 135
  temperature range, **150**
Pythiacystis gummosis, 125, **127***, **130**
  accompanying dry root rot, 105
  cause, 132

Pythiacystis gummosis,
  contributing conditions, 135
  development, 129, 130
  distribution, 126
  Fusarium as secondary aid, 138
  gummous zones, 130
  history, 122, 126
  in nursery, **67,** 68
  on lemon bark, 127
  on sweet oranges, 131
  prevention, 139
  susceptibility, 43, 137
  symptoms, 127
  treatment, **141**
  typical example, 138
Pythium,
  classification, 25
  in damping-off, 64

Q

Quarantine measures against diseases, 46

R

Red Aschersonia, 266
Red blotch, (adjustiosis), **440***
  in cold storage, 528
  symptoms, 440
Red-headed fungus, Sphaerostilbe, 268, **269**
"Red rot" (red blotch), **440***
Red spider injury, 330
Resistance,
  canker, 43
  decorticosis, 43
  diseases, 9
  in disease prevention, 42
  psorosis, 43
  pythiacystis gummosis, 43
  scab, 43
Rhizoctonia, in damping-off, 64
Rhizopus,
  classification, 25
  rot, 366
Rhodesia, mistletoe, 341
  ring blotch, 241, **242,** 243
Rhynchodiplodia citri, in Italy, 508
Ring blotch in South Africa, 241, **242**
Rodent injury, to roots, 154
Rolf's Sclerotium blight, in seed bed, 65
Rolf's Sclerotium rot, 367, **368**
Root diseases,
  Armillaria root rot, 89
  crown roots, 121
  identification key, 84
Root rot,
  Armillaria, 89
    contributing conditions, 94
    resistant species, 97
    symptoms, 89
    control, 95
  Diplodia, 120
  dry, **106, 107**
  gas and oil injury, 120
  in nurseries, 66
  Phoma omnivora, 112
  Rosellinia sp. in, 98
  Sclerotinia, 103
  Ustulina vulgaris, 112
  water injury, 109
Roots,
  effect of nematode, **114**
  insect injury, 118
  mechanical injuries, 72
  Poria fungus on, 109
  rodent injury, 154
  structure, 15
Rose-beetle, Fuller's,
  injury to leaves, 333
  injury to roots, 118
Rosellinia
  bunodes
    description, 100
    in root rot, 98
  classification, 26
  pepo (fungus)
    description, 100
    in root rot, 98, 99, 100
  root rot,
    contributing conditions, 101
    control, 102
    history and distributions, 98
    symptoms, 98
Rosette growth, with exanthema, 248
Rot of fruit, 353
  Alternaria, 389, **390***
  anthracnose, 396
  Aspergillus, 365, 366
  black rot, 393
  Botrytis, **372*,** 385
  charcoal rot, 414

Rot of fruit,
  Cytosporinia of mandarin, 465
  Diplodia, 409, **410***
  Dothiorella, **410***, 412
  Fusarium, 398
  hyaline rot, 388
  inspissosis (dry rot), 415
  Oöspora fungus, 369, **372***
  Phomopsis stem-end, 401, **402***
  Phytophthora, 379
  Pleospora fungus, 393
  Pythiacystis fungus, **372***
  Rhizopus fungus, 366
  Rolf's sclerotium, 367
  Sclerotinia fungus, 380
  stylar end of limes, 399
  Trichoderma fungus, 364, **402***
Rot of roots. See Root rot
Rots of wood, 196, **197, 199**
Rough lemon, scab on, 10, 494
Rubbing from wind injury, 511
Rubellosis. See pink disease.
Ruggine bianca, in Italy, 508
Russeting, on fruit, 503
Russia,
  Exobasidium fungus, 503
  Fusarium root rot, 108
Rust mite injury,
  on fruit, 503, **504**
  tear stain, 506

S

Sanitation in orchard, 40
Satsuma orange
  See *Citrus nobilis unshiu*
Scab (verrucosis)
  age of tissue, 490
  causal agent, 490
  conditions favoring, 492
  control, 495
  distribution, 485 **486**
  in nursery, 68
  influence of temperature and moisture, 36
  shot-hole effect, **225**
  similar to lime anthracnose, 494
  susceptibility of species, 43, 493
  symptoms on fruit, **486***, **488**
  symptoms on leaves, 222, **223, 224, 486***, 487
Scab fungus (*Sphaceloma fawceiti*), **491,** 492
  related to grape anthracnose, 491
  spore dispersal, 491
Scalding, on fruit, **523,** 524
Scale insects,
  fungi parasitizing, 264, **269**
  nature of injury, 264
  relation to disease, 264
  sooty mold with, 253
Scaly bark,
  leprosis,
    different from psorosis, 235
    in Florida, 231, **233, 234**
  psorosis,
    different from leprosis, 158
    in California, 158, **160, 162, 163***, **168, 169**
Schizomycetes (bacteria) nature of, 24
Schyzophyllum commune as wood rot, 198
Sclerotinia
  damping-off, 64
  gummosis, 153
  in nursery, 68
  libertiana, 380, 381, **382**
    characteristics, **382, 383**
    classification, 25
    development, 382
    in cold storage, 528
    in twig blight, 310
    on roots, 103, **104**
  with frost injury, 202, 279
Sclerotium
  damping-off, 64
  rolfsii
    characteristics, 367, **369**
    classification, 27
    in fruit rot, 367
    in seed-bed, 65
Scurf, from wind injury, 509, **510**
Seedbed diseases, 64
Septobasidium
  acaciæ, in Formosa, 259
  albidum, in Formosa and Brazil, 259
  bogoriense, in Formosa, 259
  fungus, on twigs, 257, **258**
    appearance, 257
    characteristics, 259
    control, 259

Septobasidium
  pseudopedicellatum (*Thelephora pedicellata*), 257
    characteristics, **259**
Septoria
  citri
    classification, 27
    in fruit spot, 477
  glaucescens, in Algeria, 477
  spots on fruit, 477, 478
Severinia buxifolia, 12
Seville orange. See *Citrus aurantium*
"Sharkskin," on fruit, 505
Shell bark, decorticosis, 176, **177**, 178
  causal agent, 180
  contributing conditions, 180
  control, 181, **182**
  distribution, 176
  due to *Phomopsis californica*, 180
  history, 176
  on *Citrus limonia*, 176, **177**
  resistance and susceptibility, 40
  symptoms, **177, 178, 179**
Siam,
  canker, 213
  mistletoe, 341
Sicily,
  mal di gomma in, 152
  psorosis in, 158
  shell bark in, 177. See also Italy
Silver mite, on fruit, 504
Silver scurf, with thrips injury, 506
Silvering, on fruit, 503
Slime molds (Myxomycetes), 24
Slug injury, 521, **523**
Smoky fungus, 500
Snail injury (slug), 521
Sodium
  chloride, effects, 318
  nitrate, effects, 318
Soil-aeration, relation to disease, 74
Solonapsis gemmenata (fire ant), inducing gum, 196
Sooty mold, 253, **254**
  control, 254
  effect on tree, 253
  on honeydew of whitefly, 265
Sour orange. See *Citrus aurantium*
Sour rot, symptoms, 369, **371, 372***
South Africa,
  anthracnose spot in, 457
  bacterial spot of, 450
  black rot in, 394
South Africa
  brown rot in, 373
  canker eradication, 212
  Diplodia rot, 409
  diseases, 30
  gummosis, 123
  investigations, **7**, 8
  melanose, 226
  Psilla on leaves, 333
  psorosis, 158
  ring blotch, 241
  scab, 486
South America,
  diseases, 33
  investigations, **7**
  nematode, 113
Sphaceloma fawcetti,
  characteristics, **491**, 492
  culture, 491
  scab due to, 490, **491**
Spain,
  Botrytis rot, 385
  nematode, 113
Specific gravity and frost injury, 433
Speckling,
  in black pit, **447**
  on fruit, 521
Sphaeropsidales, classification, 27
Sphaeropsis knot, symptoms, 322, **323**
Sphæropsis tumefaciens,
  causal agent, 325
  characteristics, 325
  control, 325
  knot due to, 322
  symptoms, 322
Sphærostilbe
  aurantiicola on insects, 265, **269**
  coccidophthora on insects, 268
  flammea on insects, 268
Splits on fruit, 517, **519**
  cause, 517
  control, 519
  nature, 517
Sporotrichum citri, scab fungus, 490, **491**
Spot,
  bacterial, South Africa, 450
  diseases, 274
Spots,
  chemical, 524
  diagnosis, 520
  heat, 524
  inherited brown, 521

Spots,
  on fruit, 440
  slug, 521
  speckling, 521
  star-shaped, 521
Spray,
  burn on fruit, **516**
  injury to fruit, 515, **516**
  injury to leaves, 279, **280**
Spraying to control disease, 41
Stag-horn growth, with exanthema, 248
Stain,
  anthracnose, 454
  in exanthema, 501
  membranous, 428
Star-shaped spot, on fruit, 521, **523**
Stellate melanose, 228
Stem-end rot,
  in lemon fruits, 538
  time of picking, 538
  See also *Diplodia natalensis*, Dothiorella and *Phomopsis citri*
Stemphyllum citri, in end rot, 394
Stereum,
  classification, 26
  in wood rot, 198
Stigminose, on leaves, Florida, 282
Stomata, relation to canker, 214
Storage,
  decay, 534, 539
  temperatures, 476
Storage, cold,
  relation to decay, 528
  temperatures, 529
Storage spot (pox), 474, **475, 476**
  control, 476
  symptoms, 474
Structure of Citrus, 13, 17
Struthanthus dichotrianthus, mistletoe, Trinidad, 342
Stylar-end rot, of Persian limes, 399, **400**
Sulfur,
  colloidal, 54
  compounds of, 52
Sumatra, pink disease, 304
Sunburning, on trunk, 201
Sweating of lemons, relation to decay, 533
Sweet lemon, scab, 10, 494
Sweet orange,
  See *Citrus sinensis*

T

Tabog. See *Chaetospermum glutinosa.*
Tahiti lime,
  psorosis, 158
  scab, 494
Tangelo,
  black pit, 448
  scab, 494
  See also Hybrids
Tangerine orange, 11. See also *Citrus nobilis deliciosa*
Tear stain. See Anthracnose
Tear staining, 505
Tear streaking, 506
Temperature,
  effects on fruit, 524
  favoring Alternaria rot, 392
  for fruit in transit, 527
  for storage, 476, 529
  in relation to,
    black pit, 449
    decay, 526
    scab, 493
  influence on
    blast, 37, 300
    brown rot, 376
    diseases, 35
    scab, 36
Tetranychus sermaculatus, injury, 331
Toxoptera aurantii (black aphis), 333
Treatment of diseases, principles of, 39
Tree surgery, 200
Trichoderma lignorum,
  characteristics of, **364,** 365
  classification, 27
  in lemon decay, 538
  on roots, 109
  rot, on fruit, **358***, 364, 365, **402***
Trifoliate orange. See *Poncirus trifoliata*
Trinidad, mistletoe in, 342
Trunk,
  diseases, 158
  frost injury, 201
  fumigation injury, **155, 156**
  identification key, 84
  lichens on, 200
  structure, 15
  sunburning, 201
Tubercularia coccicola on insects, 270
Turbinate Aschersonia, on wax scale, 268

Twig blight, due to,
  Botrytis, 311
  Diplodia, 308
  Phytophthora, 380
  Sclerotinia, 310
Twigs,
  canker, 218
  gumming, 315
  key to diseases, 207
  scab on, 226
  Septobasidium on, 257, **258**
Tylenchulus semipenetrans (nematode), 113, **115**

U

Unshiu (*Citrus nobilis* var *unshiu*), 12
  canker on, 214
Ustulina vulgaris
  in root rot, 112
  relation to water injury, 112

V

Ventilation in storage, 477
Vermicella (Cuscuta), 342
Verrucosis,
  control, 495
  in nursery, 68
  on fruit, 485, **486*, 488**
  symptoms of, 222, **223, 224**
  See also Scab
Verticillium heterocladum, on insects, 265, 272

W

Washing fruit, relation to decay, 526, 532
Water injury,
  control as related to root rot, 112
  on roots, 109
  symptoms, 110, **111**
Water relation,
  in endoxerosis, 424
  influencing diseases, 35
  to June drop, 437
Wax, grafting, 62
Webber's brown fungus (*Aegerita webberi*), 270, **271**
West Indian lime, 10. See also *Citrus aurantifolia*
West Indies,
  anthracnose of lime, 284
  Atichia fungus, 262
  charcoal rot, limes, 414
  Citrus galls, 326
  Diplodia gummosis, 190
  Diplodia rot, 409
  Diplodia twig blight, 308
  diseases, 29
  dodder, 342
  fungi on insects, 268
  greasy spot, 229
  inspissosis, 416
  investigations, 7
  Rosellinia root diseases, 98
  thread blight, 314
Whiteflies, control by fungi, 265
White-fringe fungus, on insects, 270
White-headed fungus, on insects, **269**
Whitewash, preparation and use, 56
Whitewashing frosted trees, 202
"Wilt" (blight), in Florida, 312, **313**
Wind injury,
  appearance on fruit, 509, 510
  depressed areas caused by, 513
  prevention, 513
  relation to decay, 541
  scurf, 509
Witches-broom, 327, **328,** 329
Withertip,
  spots on fruit, 454, 458, 459
  tear stain, 454, 455
  See also Anthracnose

Y

Yellow Aschersonia, 268
Yellow tip, 421
Yucatan
  exanthema, 244
  mistletoe, 341
  Rosellinia root disease, 98